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ABSTRACT

This booklet is the first in a series of Environmental Resource Packets designed to encourage college science teachers to become professionally competent in selected environmental areas of study. Produced unver a grant from the ESSO Education Foundation, each packet will consist of a review paper(s) and a selected and annotated bibliography which considers not only the natural sciences but also economics, politics, ethics, etc. In this packet dealing with energy and the environment, Part One is a three-segment paper which studies (1) energy: where it comes from and where it goes, (2) environmental effects of energy use, and (3) resources and new sources. Part Two, which contains the annotated bibliography, covers basic general references, energy policy, electric power, nuclear power, fossil fuels, energy resources, future sources of energy, data, and student reading selections. Cross references are noted at the end of each section also. Each entry delineates the title, author's name, publisher, point of view, level of use, and a summary of the contents. (BL)

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ENERGY AND THE ENVIRONMENT

J. M. FOWLER AND K. E. MERVINE

JANUARY 1973

An Environmental Resource Packet published under a Grant from the ESSO Education Foundation.

SE 015 932

PREFACE

This is the first of a series of "Environmental Resource Packets" which we are producing under a grant from the ESSO Education Foundation.

The overall goal of this project is to encourage college science teachers to become professionally competent in selected environmental areas. We wish to make it attractive and possible, through the collection, selection, and summaries which go into each packet, for teachers to become resource people for their local communities and/or to incorporate substantial environmental materials into their college courses. It is our hope that both of these approaches will serve to lessen some of the "antiscience" feeling that has developed in this country over the past few years.

Each packet will consist of a review paper (or papers) and a selected and annotated bibliography. In both the review paper and the bibliography we are making a determined effort to reach beyond the natural sciences and bring in considerations of economics, politics, ethics, etc. as they apply. We are also attempting by our selection of articles to represent all the points of view which are important to the environmental problems which the packets deal with.

The selection of the books and articles whose summaries make up the major content of these packets is guided by several criteria. Among them are:

1) Availability: Is the reference (book or journal article) likely to be available through most libraries or easily obtained from some other source?

2) Coverage: Does the reference cover material not covered in another of the packet entries?

3) Length: Is the article long enough (about 4 pages) to make its selection worthwhile?

4) Level: Is the reference written at a level which makes it useful to a non-specialist audience?

5) Balance: Do the references selected cover the variety of viewpoints from different disciplines and different biases - that need to be presented?

We have modest expectations for these Environmental Resource Packets; we have tried only to eliminate the library search and extensive first readings that is a barrier for the busy college science teacher. We hope that it will be possible, with the help of these packets, for each teacher to select just those references which are appropriate to the level and emphasis of the presentation he wishes to make. The design of a topic presentation, to a class or to a popular audience, obviously is a task for the individual teacher. If such design is encouraged and made easier by the existence of these packets then the goals of both the ESSO Education Foundation and the authors of these packets will have been well served.

J. M. Fowler
K. M. Mervine
January 1973

Postscript:

With this first packet we include a questionaire. Please fill it out after you have made use of the packet and return as quickly as possible. Your responses will be valuable to us as we design and complete the further packets in this series.

We also apologize for the "anti-environmental" waste of paper in our printing of the review paper on only one side. This was a printer's error which will not reoccur.

ENERGY AND THE ENVIRONMENT

John M. Fowler

Dr. Fowler is a visiting professor in the Department of Physics and Astronomy at the University of Maryland, College Park. This discussion of energy is adapted from Dr. Fowler's Sunoco Science Seminar presentation at the 1972 convention of the National Science Teachers Association in New York City April 8–10.

I

ENERGY: WHERE IT COMES FROM AND WHERE IT GOES

THE WORLD runs on energy, both literally and figuratively. It spins on its axis and travels in its orbit about the sun; the winds blow, waves crash on the beaches, volcanoes and earthquakes rock their surroundings. Without energy it would be a dead world. Energy was needed to catalyze the beginning of life; energy is needed to sustain it.

For most of life, animal and plant, energy means food; and most of life turns to the sun as ultimate source. The linked-life patterns—the ecosystems—which have been established between plants and animals are very complex; the paths of energy wind and twist and double back, but ultimately they all begin at that star that holds us in our endless circle.

When man crossed that threshold of consciousness which separated him from animals, his uses of energy began to diversify. He, too, needed food, but poorly furred as he was, he also needed warmth. With the discovery of fire he was able to warm himself. He also found that fire could make his food digestible and thus increase its efficiency as an energy source. After a while he began also to use fire to make the implements through which he slowly started to dominate nature.

Man's use of energy grew very slowly. In the beginning he required only the 2,000 or so Calories [1] per day for food; the convenience of warmth

[1] We will consistently deal with Calories (kilocalories), the amount of heat energy needed to raise the temperature of one kilogram of water one degree Celsius.

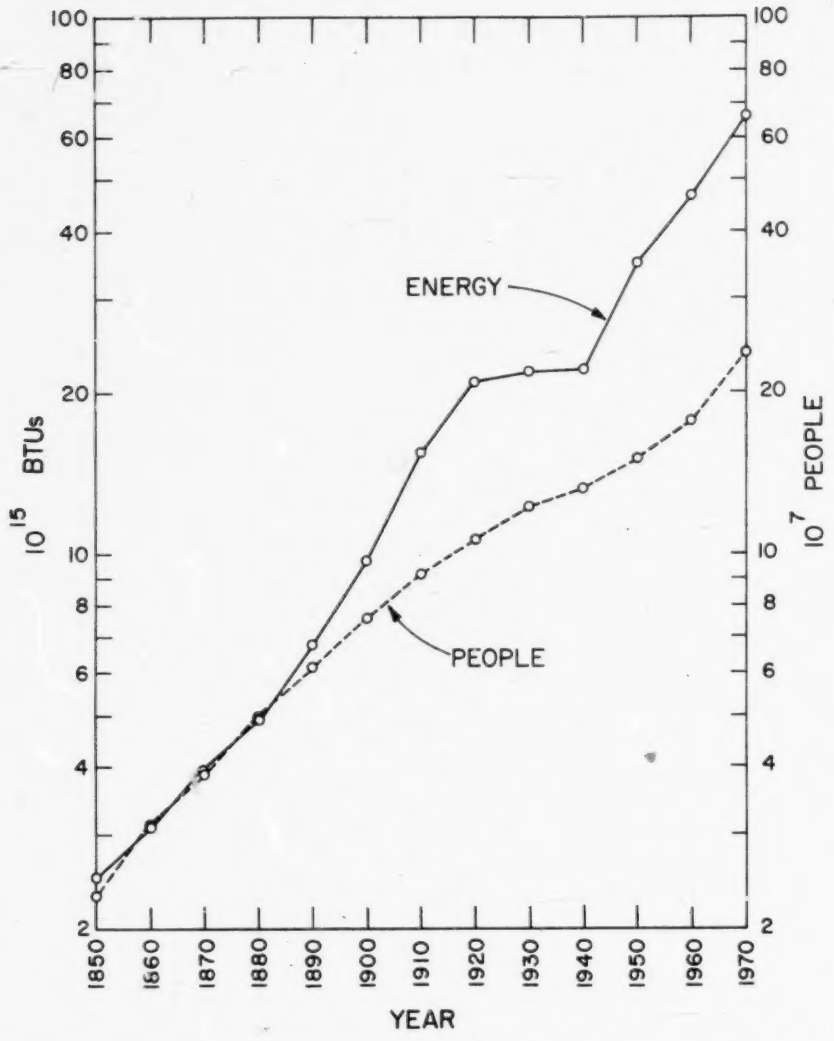


Figure 1. Comparison of energy and population growth, United States, 1850-1960.

added a few thousand more Calories from easily obtainable wood. The first big jump in energy use came about four or five thousand years BC when man domesticated several animals and —at the cost of a little food, much of which he gathered himself—was able to triple the amount of energy at his service.

The waterwheel appeared in the first century BC and again multiplied the amount of energy available to man. Its introduction was perhaps even more significant because it was a source of inanimate energy. For a long time the waterwheel was the most important source of energy for the nascent industry. It was not until the twelfth century, more or less, that the analogy between flowing air and flowing water led to the use of windmills.

The beginning of the modern era of industry coincided with the development of the steam engine. Since that time the world's use of energy, which until then had been very nearly proportional to the number of people, began to grow in the industrial countries more rapidly than the population increased. This growth, shown in Figure 1 for the United States, continues.

The second historical trend which, together with the increasing per capita use, has brought us to the present state, is the constant change in the energy mix. Wood was the dominant fuel in the 1850s but had lost all but 20 percent of the market to coal by 1900. Coal in turn lost out after 75 years to petroleum products, which now account for 75 percent of the energy, but they in turn will be (and *must* be as we shall see) replaced by other sources. Nuclear energy is the best present candidate.[2]

Energy as a Commodity

In the early stages of man's history, energy was food, something to be found and consumed. But as life became more complex, and early barter systems were followed by a money-based economy, energy had to be bought. At first it was purchased indirectly as food or fuel. With the introduction of electricity, energy could be piped directly into the house or factory.

Energy is a commodity; it can be measured, bought, and sold. But its price depends on the form in which it is purchased—as food or fuel or electricity. Table 1 is an "energy shopping list." It is clear that we pay for the good taste of energy in the form of steak but even more for the convenience of electricity.

Table 1. Energy values for some fuels and foods (retail prices).

Source	Energy (Cal/kg)	Energy (kWh/lb)	Energy (cost/1000 kWh)
Coal	7,200	3.86	$ 5.20
Fuel Oil	10,800	5.72	4.30
Natural Gas	11,000	5.86	5.46
Gasoline	11,530	6.10	10.00
Alcohol*	6,400	3.42	10.25
Alcohol**	2,580	1.37	2,920.00
Bread	2,660	1.42	220.00
Butter	7,950	4.20	200.00
Sugar	4,100	2.16	68.00
Sirloin	1,840	.94	1,640.00
Electricity	---	--	20.00

*denatured, ** Scotch, 80 proof

Where It Goes

The energy crisis is not a crisis caused by the "using up" or the disappearance of energy. The First Law of Thermodynamics assures us of that. Energy is conserved, at least in the closed system of the universe. The crisis must then be found in the pathways of energy conversion.

[2] See Cook, E. "The Flow of Energy in an Industrial Society." *Scientific American* 225: 134-144; September 1971.

We use energy in its kinetic form, as mechanical energy, heat, or radiant energy. The form in which it is stored is potential energy. We know from physics that the potential energy of a system is increased by ΔE when we operate against a force over a distance ΔX, i.e.,

$$\Delta E = \vec{F} \cdot \vec{\Delta X}$$

In the infinite variety of the universe we have, so far, discovered only three types of forces: gravitational, electrical, and nuclear (there seem to be two nuclear forces corresponding to the weak and the strong nuclear interaction). It follows, therefore, that there are three primary sources of energy: gravitational, electrical (chemical), and nuclear. On the scale of the universe these are the most important, and the weak force, gravitational, and the strong one, nuclear, give us the most visible effects.

At earth's scale we choose other primary sources of energy. Solar energy, radiated from the thermonuclear processes in the sun, is the most important of these. It gives us the kinetic energy of water power and wind power, warms us, is stored as chemical energy in growing things, and was preserved in the fossil fuels.

We store the gravitational energy of lifted water in reservoirs, but the only true primary source of gravitational energy of which we make commercial use (in a small way, admittedly) is that of the tides. Here we draw on the gravitational energy stored in the earth-moon system.

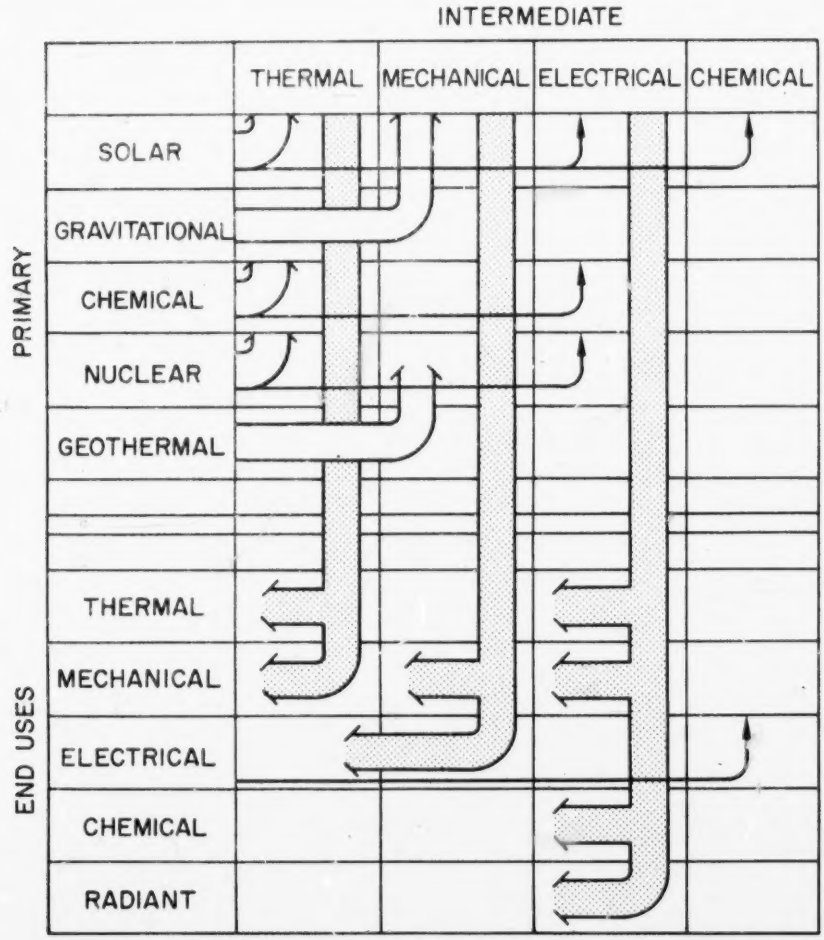
We show these and the other important primary sources of energy in Figure 2. The chemical energy of fossil fuels is at present far and away the most important of these, but there are two non-solar sources, geothermal energy from the earth's heated interior (originally heated by gravitational contraction and kept warm by radioactivity) and the new entrant onto the scene, nuclear energy.

Excepting solar energy, the other primary sources are of little direct use to us; they must be converted to the intermediate forms and often converted again to the end uses which are also shown schematically in Figure 2.

The major sources of energy in this country are the chemical energy of the fossil fuels. From them we get 95.9 percent of the inanimate energy we use. They are fuels; their chemical energy is released by burning. Thus the major conversion pathway is from primary chemical energy to intermediate thermal energy. In fact, most of the conversion pathways go through the thermal intermediate form.

We will look later in detail at the distribution of energy among the various end uses. We know in advance, however, that the major end uses are thermal (space heating, for example) and mechanical. Mechanical energy is also a major intermediate form and is also converted to that most important intermediate form, electrical energy. The convenience of electrical energy shows up in its ready conversion to all the important end uses.

Figure 2. Paths of energy conversion.



Conversion Efficiency

The most important conversion pathway is thus chemical → thermal → mechanical; and here we enter into the domain of the Second Law of Thermodynamics. It is this "thermal bottleneck" through which most of our energy flows that contributes mightily to the various facets of the energy crisis. We burn to convert, and this causes pollution. We are doomed to low efficiencies by the Second Law, and the wasted heat causes "thermal pollution." Let us consider the efficiency problem first.

Efficiency, the ratio of output work to input energy, varies greatly from

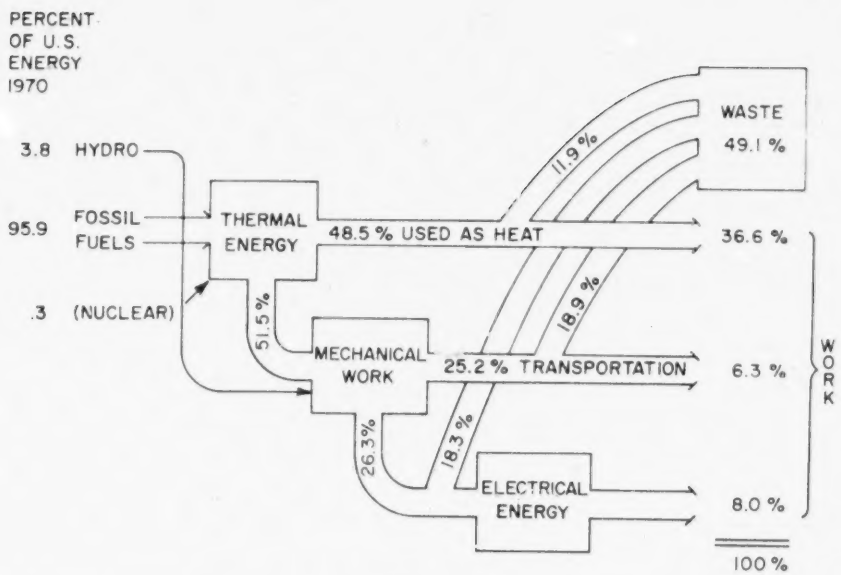


Figure 3. The flow of energy in the United States.

conversion to conversion. Generally speaking, we can convert back and forth from electrical energy to other forms with high efficiency, but when we convert other forms of energy to heat and then try to convert heat to mechanical energy we enter the one-way street of the Second Law.[3]

The efficiency of a "heat engine" (a device for converting heat energy to mechanical energy) is governed by the equation:

$$\text{Eff.} = \left(1 - \frac{T_{out}}{T_{in}}\right) 100$$

where T_{in} and T_{out} are the temperatures of intake and exhaust. This equation sets an upper limit of efficiency (it is for a "perfect" Carnot cycle). Since we are forbidden $T_{out} = 0°K$ or $T_{in} = \infty$, we are doomed to the intermediate range of modest efficiencies. For example, most modern power plants use steam at 1,000°F (811°K) and exhaust at about 212°F (373°K) with a resulting upper limit of efficiency of 63 percent. The actual efficiency is closer to 40 percent. Nuclear reactors presently operate at a T_{in} of about 600°F (623°K) and T_{out} of 212°F (373°K) for an upper limit of 40 percent. They actually operate at about 30 percent. In an automobile the input temperature of 5,400°F (3,255°K) and output of 2,100°F (1,433°K) would allow an efficiency of 56 percent. The actual efficiency is about 25 percent.

So far we have talked about the efficiency of the major conversion process, heat to mechanical work. What is more important to an understanding of the entire energy picture, however, is the system efficiency; for example, the overall efficiency with which we use the energy stored in the petroleum underground to move us down a road in an automobile. Table 2 shows the system efficiency for transportation by automobile and the production of electric power. One can see that overall there are large leaks in the system and that most of the available energy is lost along the way.

"Lost" does not, of course, describe precisely what happens to energy. We know what happens; it is converted to heat. The inexorable Second Law describes the one-way street of entropy. All energy conversion processes are irreversible; even in the highly efficient electrical generator some of the mechanical work goes into unwanted heat. The conversion of other forms of energy to heat is a highly efficient process—ultimately 100 percent. It is a downhill run. But the reverse is all uphill; heat energy can never be completely converted to mechanical work. The potential energy available to us, whether it be chemical, nuclear, or gravitational in form, is slowly being converted to the random motion of molecules. We cannot reverse this process, we can only slow it down.

Patterns of Consumption

Ever since President Johnson turned off the lights in the White House there has been a small (too small) but growing effort to save energy. It seems reasonable that this country and perhaps all countries will, at least for a while, have to make a real effort in this direction. To produce measurable effects, however, these efforts will have to be aimed at important sections of consumption.

A gross flow chart of energy in our economy is shown in Figure 3. One sees the thermal bottleneck. Heat is the desired end product from about half of our energy. We do use that amount of energy efficiently. Of the half that goes to provide mechanical work, however, large amounts are lost in the production of electrical energy and transportation. The net result is that overall (and one must remember here that we are dealing with refined fuels delivered to the converters) our system is about 50 percent efficient.

Table 2. Energy system efficiencies.

	Efficiency of Each Step	Efficiency Including All Preceding Steps
	Percent	*Percent*
Automobile		
Production of crude petroleum	96	96
Refining of petroleum	87	83.5
Transportation of gasoline	97	81
Thermal efficiency of engine	29	23.5
Mechanical efficiency of engine	71	16.7
Rolling efficiency	30	5
Electric Power Generation		
Production of coal	96	96
Chemical energy of fuel → boiler heat	88	84.5
Boiler heat → mechanical energy	50	42.3
Mechanical energy → electrical energy	99	42
Transmission efficiency	80	33.5

[3] See Summers, Claude M. "The Conversion of Energy." *Scientific American* 224: 149-160; September 1971.

II

ENVIRONMENTAL EFFECTS OF ENERGY USE

Patterns of Consumption

The intimate connections between energy, our way of life, and the natural environment occur at many places. The most important points are, of course, in the production of energy—in the mines and wells, refineries and generating plants—and at the points of consumption. Figure 3 gave a crude picture of consumption; we need to look at it in more detail.

Figure 4 gives both a crude breakdown and details of the 60,526 trillion BTUs of energy in each category. One sees that industry and transportation use the lion's share. The importance of space and water heating also shows up strongly. Predictions are that transportation and commercial use will be the fastest growing sectors.[4]

Electrical Energy—
The People's Choice

What doesn't show up in this presentation is the special case of electrical energy. It is there, contributing heavily to all categories except transportation, and it shares with transportation most of the blame for energy's role in environmental degradation.

The growth rate of electrical energy consumption, shown in Figure 5, is the highest of all the various forms of energy. In discussing growth a most useful concept is "doubling time." The energy curve of Figure 1 shows several different periods of growth and, therefore, several different doubling times. In the late 1800s the doubling time was about 30 years; by the early 1900s this had been cut in half to about 16 years. The doubling time during the growth period from 1950 to 1960 was 25 years, and for the period 1960 to 1970 dropped to 18 years.

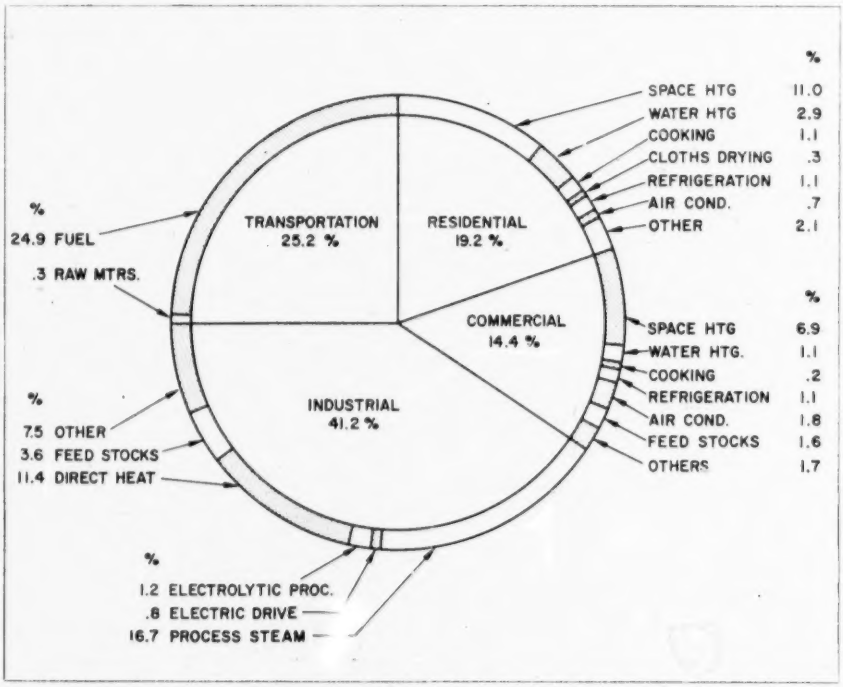
Electrical energy can be said to have arrived commercially with the start-up of the Pearl Street Station by Thomas Edison in 1882. (The energy curve in Figure 1 breaks away from the "people" curve by about 1890.) The doubling time for per capita electrical energy consumption of Figure 5 was only 7½ years during the start-up period of 1910 to 1920, was about 14 years in the 1950s and 60s and has decreased to about 10 years now. This means that in the period 1970 to 1980 the per capita use of electrical energy will be expected to double.

The impact of electrical energy can be better understood from the plot of total electrical energy consumption also shown in Figure 5. This curve has been doubling every 10 years since 1950. This means that in each of those 10-year periods the United States used as much electrical energy as in its entire previous history.

The reasons for the rapid increase in demand for electrical energy are several. It is in many ways the most convenient of the forms of energy. It can be transported by wire to the point of consumption and then turned into mechanical work, heat, radiant energy, or other forms.

It cannot be very effectively stored, and this has also contributed to its increasing use. Generating facilities have to be designed for peak use. In the late 50s and early 60s this peak

Figure 4. U.S. energy consumption 1971 (total 60.5 x 10^{15} BTUs).



[4] Landsberg, H. H., and S. H. Schurr. *Energy in the United States: Sources, Uses and Policy Issues.* Random House, New York. 1960. P. 76.

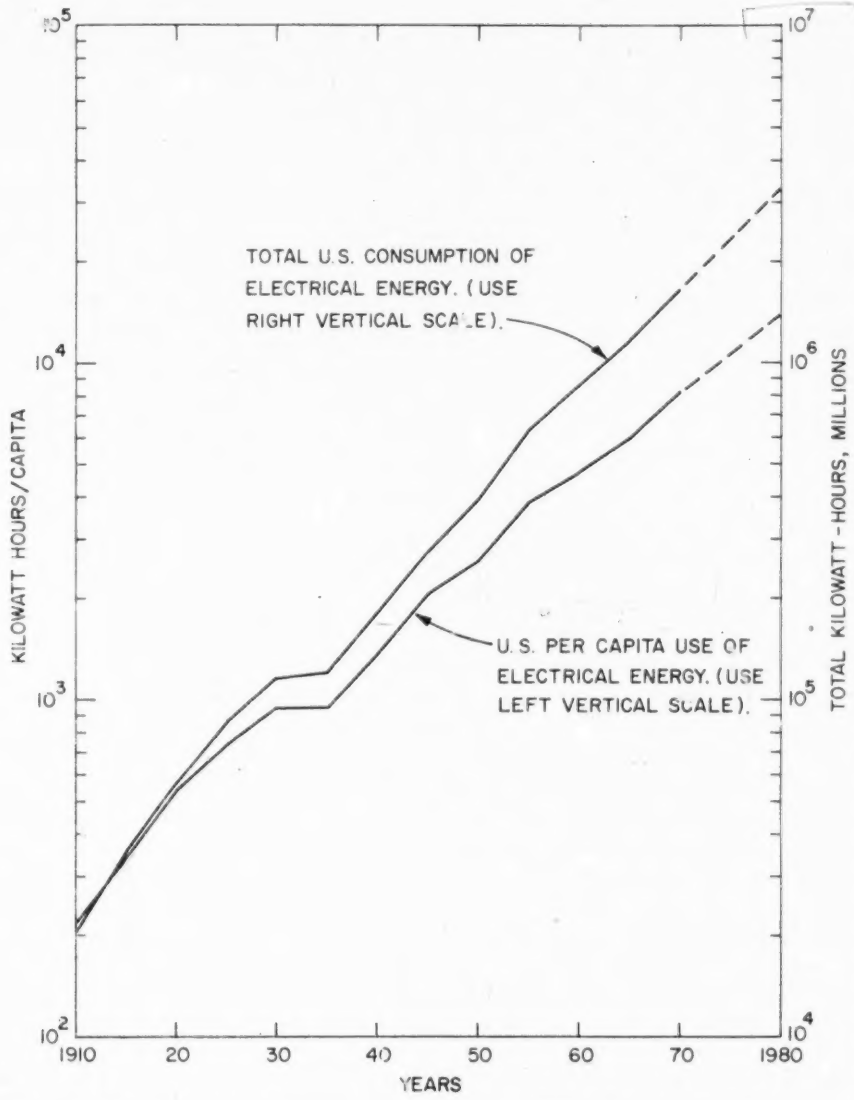
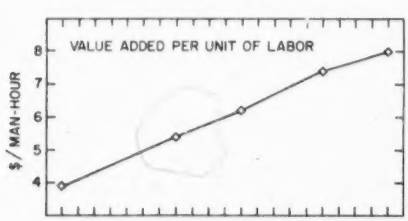


Figure 5. Growth of electrical energy consumption in the United States since 1910.

came in the winter, when nights were longer and more lighting and heating were needed. It was economically sound to heavily promote off-peak use, such as summer use of air conditioners. This promotion was so effective that the summer is now the peak time, and the sales effort seems to be going into selling all-electric heating for off-peak winter use.

The rate structure has also contributed to increasing use of electrical energy. Rate reductions are offered to attract bulk consumers. Hindsight suggests that there has been an imbalance between research and promotion. The figures bear this out. Senator Lee Metcalf has reported that the utilities in 1969 spent $323.8 million on sales and advertising and $41 million for research and development.

Figure 6. Labor productivity in the period 1947-1968.



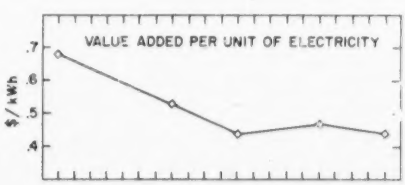
Perhaps the most important clue to the great increase in the use of electrical energy was suggested by Barry Commoner in an address to the American Association for the Advancement of Science.[5] Commoner looked at the important economic parameter "productivity," which is defined as the ratio of value added to a product/man-hours to produce it. The strength of the economy is built on increasing productivity. The data Commoner presents, for the period 1947 to 1968 (Figure 6) show that labor productivity has been steadily increasing. He and his colleagues then looked at the history of electric power productivity. These two quantities, man-hours and kilowatt-hours, do play similar roles in industry—electricity amplifies the existing muscle power in many cases. This analysis of electric power productivity showed the very different results of Figure 7. The ratio of value added to kilowatt-hours/electric power productivity, declined sharply from 1947 to 1958 and has flattened out since then. This suggests the important conclusion (which merits much more careful study) that the increase in labor productivity has been bought, at least partially, at the expense of a decrease in power productivity. Since labor is more expensive than electric power, the effects on the economy have been beneficial. But what about effects on the environment?

Environmental Effects: Air Pollution

There are two major areas of pollution, air and thermal, which are almost completely attributable to energy consumption. Air pollution is unhappily well known to all of us through smog—

[5] Commoner, Barry. "Power Consumption and Human Welfare." Paper prepared for delivery at the annual meeting of the American Association for the Advancement of Science. December 29, 1971.

Figure 7. Electric power productivity in the period 1947-1968.



that collection of irritating hydrocarbons and oxides of sulfur and nitrogen which is becoming a fixture of urban living. Table 3 gives a breakdown of the contributions to pollution of the various categories of polluters. One sees that the generation of electric power is the major source of sulfur oxides, while the automobile leads for three other pollutants.

It is of course not possible to deduce the importance of these pollutants from their gross weight because they have very different effects. Some, like carbon monoxide, affect health in even minute concentrations, others, like the particulates, largely add to cleaning bills. This article is not the place for a detailed discussion of the effects of air pollution.[6] We will simply summarize the costs, which come from effects on the health, damage to crops and exposed materials, and property values, by quoting the Second Annual Report of the Council on Environmental Quality, August 1971.

> The annual toll of air pollution on health, vegetation and property values has been estimated by EPA at more than 16 billion dollars annually—over $80 for each person in the United States.[7]

The dependence of our society on the automobile for transportation presents us with a complex mix of problems; in addition to polluting the air, it uses one quarter of our energy total in a very inefficient way, leads to the covering of our countryside with concrete, contributes to many aspects of the problems of our cities, and takes a high toll of human life. The discussion of these problems and suggestions for solutions are fascinating and important, but cannot be undertaken here.

The generation of electric power at present depends almost entirely on the burning of the fossil fuels. The sulfur oxides come from the sulfur impurities in these fuels. The burning of these fuels also converts large amounts of carbon to carbon dioxide. This familiar gas is not a pollutant in the ordinary sense, but its steady increase in the atmosphere is a cause for concern. Carbon dioxide is largely transparent to the incoming short-wave solar radiation, but reflects the longer-wave radiation by which the earth's heat is radiated outward, producing the so-called "greenhouse effect." Presently about six billion tons of CO_2 are being added to the earth's atmosphere per year, increasing its CO_2 content by 0.5 percent/year. By the year 2000 the increase could be as much as 25 percent. Our understanding of the atmosphere is not sufficient to predict the eventual effects on climate which might be produced by this increase and by a related increase in water vapor and dust, but small changes in the average temperature could have catastrophic effects.

Nuclear Reactors—Clean Power?

There are strong forces in this country pushing the nuclear reactor as an answer to our need for clean power sources. The reactor gains its energy from the fission of U^{235} or Pu^{239}. The energetic by-products of this fissioning are stopped in the fuel rods, heating them, and this heat is transferred by some heat exchanger to a conventional steam-powered electric generator.

The fission products are radioactive, dangerously so. They have many different half-lives, but the whole mess averages a half-life of perhaps 100 to 150 years. The switch to nuclear energy for the generation of electricity will be accompanied by a growing problem of disposal for this radioactive waste. Snow[8] has estimated that the 16 tons of radioactive fission products from reactors accumulated in 1970 will have grown to 388 tons by 1980 and will be more than 5,000 tons by the year 2000.

Nuclear reactors are carefully designed against the release of these products which are collected and stored for safety. But the storage problem itself is a far from negligible one, with no generally agreed-on solution in sight. It has been proposed that the most dangerous wastes be dried and stored in salt mines in Kansas. There are now indications that above-ground storage will be the approved means.

So far the radioactivity associated with nuclear reactors seems to have been handled with exemplary safety. Any exposure to the general population from this source is in the range of present exposure from past nuclear testing. It is in all likelihood causing damage, but so do all the other forms of power generation.[9] What really must concern us when we consider substituting the fissioning of uranium for the burning of fuel is the possibility of accident.

When discussing accidents, we are not talking about a real nuclear explo-

[6] *Air Pollution*, a Scientists' Institute for Public Information Workbook. SIPI, 30 East 68th Street, New York.

[7] *Environmental Quality*, the second annual report of the Council on Environmental Quality, August 1971. U.S. Government Printing Office, Washington, DC. P. 107.

[8] Snow, J. "Radioactive Waste from Reactors: The Problem that Won't Go Away." *Science and Citizen* (Environment Magazine) 9: 89-95; May 1967.

[9] This is treated more fully in *The Environmental Cost of Electric Power Production*. A SIPI Workbook. SIPI, 30 East 68th St., New York.

Table 3. Estimated emissions of air pollutants by weight nationwide, 1969; total 281.2 million tons[a] (in millions of tons/year).

	Carbon Monoxide		Particulates		Sulfur Oxides		Hydrocarbons		Nitrogen Oxides		Total
Source	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount
Automobile	111.5	74	0.8	2	1.1	3	19.8	53	11.2	46	144.4
Power plants	1.8	1	7.2	21	24.4	73	.9	2	10.0	42	44.3
Industrial	12.0	8	14.4	41	7.5	22	5.5	15	.2	1	39.6
Refuse burning	7.9	5	1.4	4	.2	1	2.0	5	.4	2	11.9
Miscellaneous	18.2	12	11.4	32	.2	1	9.2	25	2.0	9	41.0
Total	151.4	—	35.2	—	33.4	—	37.4	—	23.8	—	281.2

[a] Council on Environmental Quality. *Environmental Quality*. P. 212. (See also footnote 7.)

sion in which a "critical mass" of fissionable material accumulates and goes off. The low enrichment densities preclude that. But since the reactor core is a witches' caldron of radioactive waste products, any accident which opens that up and spreads it over the countryside is catastrophic. The accident that designers fear is cooling system failure. If the cooling-water were somehow denied the fuel rods, in only a matter of seconds they would begin to melt, leaving the reactor core an uncontrollable blob of melting metal, heated internally so that it continues to melt. The resulting steam pressure explosions then could release the radioactivity to the environment. It is this small but troublesome chance of accident that keeps reactors away from the cities where their products, electricity and heat, are needed.

Heat as a Pollutant

As we have earlier stressed, energy conversion is largely a one-way street: All work eventually produces heat. The "heat engines," because of their inefficiency, however, are particularly troublesome. A steam power plant, which is only 30 percent efficient, dumps two units of heat energy for every one it converts to electricity. As our appetite for electricity grows in its apparently unbounded way, so also grows the problem of heat discharged to the environment.

In the steam power plant the waste heat problem is associated with the necessity to lower the temperature of the exhaust steam (so that the piston will not have to work against an appreciable back pressure). The most inexpensive and convenient way to accomplish this is to divert water from a stream or river. Nuclear reactors, since their working parts are steam engines, have the same problems. In fact, the nuclear reactor, because of its lower efficiency, presents a more serious cooling problem. Because of the difference in power plant efficiencies (30 percent versus 40 percent) and in fuel efficiency, and because the fossil-fuel plant discharges about 10 percent to the atmosphere through its stack, the reactor dumps about twice as much heat per kilowatt hour of energy produced as does the fossil-fuel plant.

We do not need to look ahead very far to see that this heating up of the environment cannot go on. There are two different sorts of projections that make this point.

The first of these concerns the cooling-water needs. If the growth of Figure 5 continues, we will need one-sixth of the total fresh-water run-off of this country to cool our generating plants by 1990 and one-third by the year 2000.[10] Long before we reach that point we will have to make some hard decisions about stream and river use and plant siting if we are to preserve inland aquatic life.

The second projection is even more indicative of the problem. If we express our consumption of electricity in terms of energy released per square foot of U.S. land area, we obtain for 1970, .017 watts/ft^2. At our present doubling time of 10 years for electric power consumption, in 100 years we will have gone through 10 doubling periods, and the energy release will be 17 watts/ft^2—almost the same as the 18 or 19 watts/ft^2 of incoming solar energy (averaged over 24 hours). Long before we reach such a level, something will have to be changed.

These two projections only serve to emphasize what should by now be obvious: Energy use, particularly electric power, cannot be allowed to continue to grow as it has. There are other data that reinforce this conclusion. Electricity means power plants and transmission lines; doubling consumption means doubling these. There are now about 300,000 miles of H.V. transmission lines occupying four million acres of countryside in the United States. By 1990 this is projected to be 500,000 miles of lines occupying seven million acres.[11]

All this serves to make the point that exponential growth cannot continue. But we could have learned that from nature. Exponential growth is unnatural; it occurs only for temporary periods when there is an uncoupling from the constraints of supply and of control. For instance, it will be demonstrated for a while by the growth of a bacterial population with plenty of food, but will eventually be turned over either by exhaustion of the food supply or by control from environmental processes which resist the population growth. We have examined some of the areas of environmental damage which may cause us to resist continued growth of energy production and consumption. What about our energy sources; are they likely to be the controlling factor?

[10] Federal Power Commission Staff Study. "Selected Materials on Environmental Effects of Producing Electric Power." Joint Committee on Atomic Energy. August 1969. P. 323.

[11] Energy Policy Staff. "Electric Power and the Environment." Office of Science and Technology. August 1970. U.S. Government Printing Office. Washington, DC.

III

RESOURCES AND NEW SOURCES

Before we ask for a statement of the lavish deposits nature has made to our energy account, we must shed our parochial view and briefly look at energy consumption as the world problem it is.

Energy and the GNP

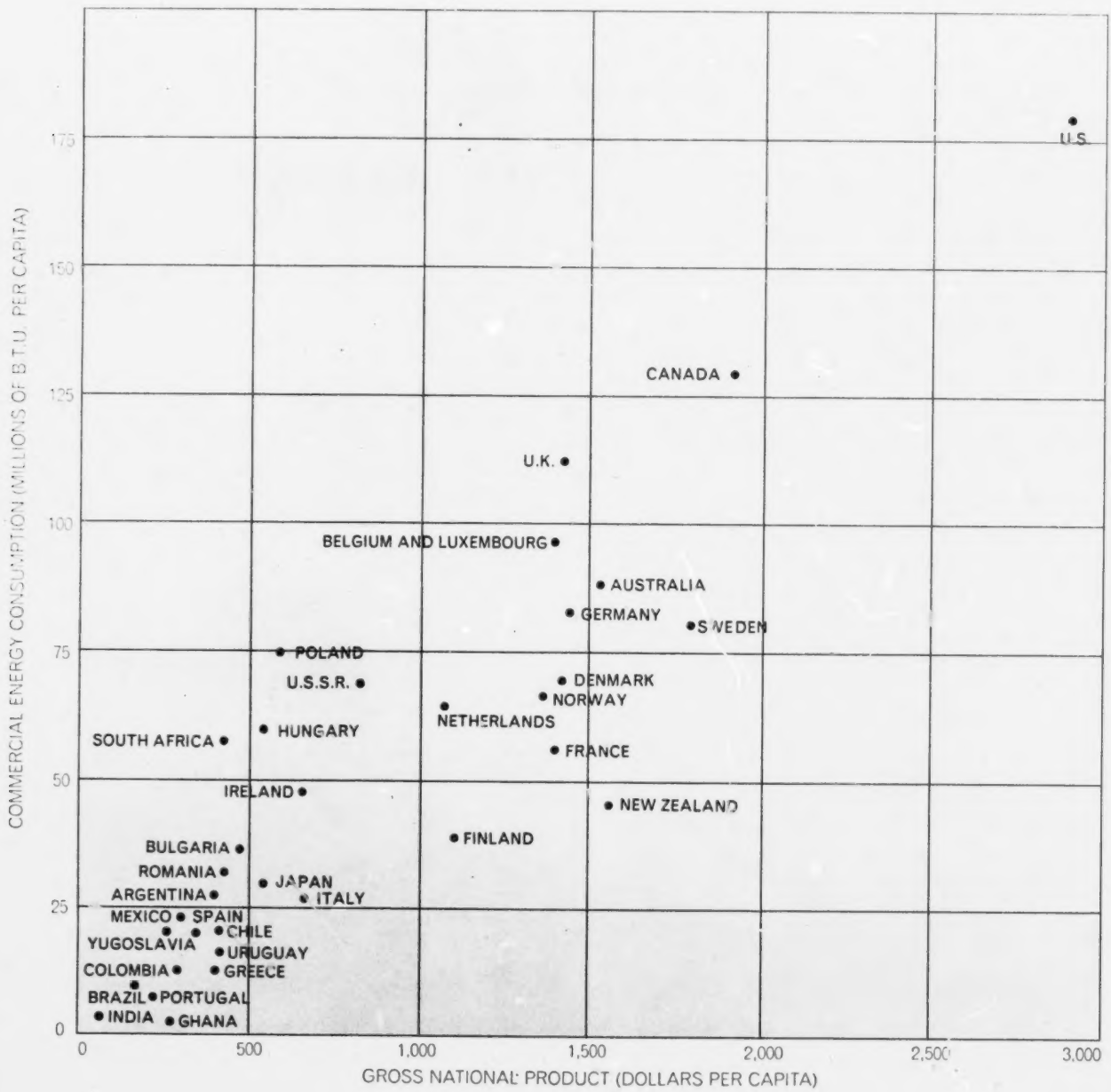
It can and will be argued that man can live happily and productively at rather low levels of energy consumption. The fact remains, however, that today per capita energy consumption is an indicator of national wealth and influence—of the relative state of civilization as we have defined it. That this is so is seen most clearly by plotting that talisman of success, the (per capita) gross national product (GNP)

against the (per capita) energy consumption shown in Figure 8. There appears a rough proportionality between per capita GNP and per capita energy consumption with the United States at the top, and countries like Portugal and India near the bottom. To the right of the "band of proportionality" lie the countries which manage a relatively large GNP with a relatively small energy expenditure. Perhaps they are worthy of study.

There are two lines of interest which lead out from this kind of data and bear on future uses of energy. One is to look at the time dependence of GNP/energy data. Data for the United States show two interesting effects.

We find a long period, 1920 to 1965, during which the country was progressively more efficient in its energy use or at least managed to increase its per capita GNP more rapidly than its per capita energy expenditure. This was apparently largely due to increased efficiency of conversion and end-use techniques. This trend reversed, however, around 1965, and we now are in a period during which this ratio is rising steadily. Reasons for this seem

Figure 8. Per capita consumption of energy and gross national product for some countries of the world. From Cook, Earl. "The Flow of Energy in an Industrial Society." Scientific American 224:142; September 1971.



to be in part at least due to a rise in non-GNP connected energy uses, such as heating and air conditioning. Since these uses are on the increase and since we are near ultimate efficiency in most of our major conversion and end-use techniques, this rise in energy consumed per dollar of GNP is expected to continue for a while and must be built into energy use projections.

The second line of inquiry concerns ultimate world use. The United States, with 6 percent of the world's population, uses 35 percent of the world's energy. If we look at comparative rates of growth, we see that the U.S. per capita energy consumption is much larger (a factor of about 30) than that of India, for instance, and is growing more rapidly. The world figure is some five times smaller but is growing a bit more rapidly than is the U.S. figure.

Even if the United States were to stabilize at the present per capita figure of 250 kWh/day, it would take about 120 years for the world per capita average to equal it and hundreds of years for India at its present rate of growth to catch up.[12] If some sort of equalization of world energy use is what we are aiming at, with the present U.S. figure as target, then we are talking about increasing world consumption by a factor of about 100. And this brings us to energy resources.

How Long Will They Last?

As someone said, "Prophecy is very difficult, especially when it deals with the future." Predicting the lifetime of energy resources is doubly difficult. Energy use curves must be projected and then unknown resource potentials guessed at. It is difficult to hope for much accuracy in either of these processes.

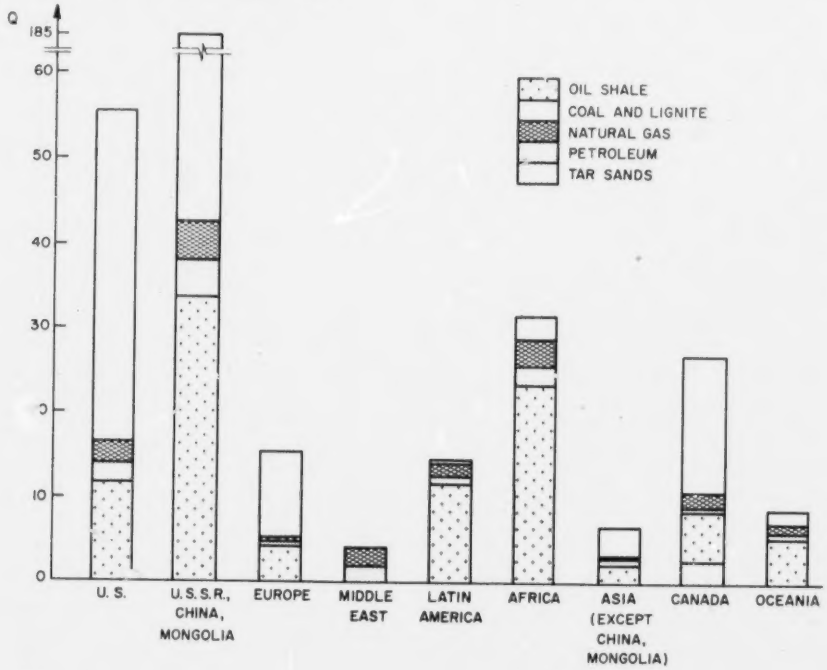
The estimation of resources is based on general knowledge of the kind of geological conditions associated with the resource and on detailed knowledge of the distribution and extent of a resource within a favorable geological area. Coal is the easiest to work with, for it seems almost always to appear where it is predicted. Oil and natural gas on the other hand are erratic in distribution within favorable areas and are found only by exploration. In addition to coal, oil, and natural gas, there are two other sources of organic carbon compounds which are potential fuel sources, the so-called tar sands and oil shale. In the tar sands, which so far have been found in appreciable amounts only in Canada, a heavy petroleum compound (tar) binds the sands together. A Canadian refinery is currently producing oil products from this material. Oil shale is shale rock containing considerable amounts of a solid organic carbon compound (kerogan). Oil can be extracted by heating the rocks, but this process has not yet been demonstrated to have commercial viability.

In Figure 9 we show the estimates of world fossil fuel resources of various types and the global distribution of these resources.[13] The unit used to measure these resources is the Q, 10^{18} BTUs. As a crude reference to the size of a Q, it would take about that much energy to boil Lake Michigan. Perhaps more useful is the fact that U.S. total energy consumption in 1970 was about 0.07 Q, and world consumption about 0.2 Q.

One sees from these data that most of the remaining fossil-fuel resources, for the United States and for the world, are in the form of coal.

Presenting data on resources does not by itself answer the question "How long will they last?" To answer that question one has to look at data on the rate at which the resources are being used. A simplified but very graphic way of displaying this has been adopted by M. King Hubbert of the U.S. Geological Survey.[14] Since supplies of fossil fuels are finite, the curve which traces their production rate will be pulse-like, that is, it will rise exponentially in the beginning, turn over when the resources come into short supply, and then decay exponentially as the resources become harder and harder to find. Such data for U.S. oil and U.S. coal are displayed in Figures 10 and 11.

Figure 9. Remaining recoverable energy resources by region. From Williams, R. H. and K. Fenton. "World Energy Resources: Distribution, Utilization, and Long-Term Availability." (See footnote 13.)



[12] These points are discussed in more detail in Starr, C. "Energy and Power," and Cook, E. "The Flow of Energy in an Industrial Society." *Scientific American* 224: 37-49 and 134-144, respectively; September 1971.

[13] Williams, R. H., and K. Fenton. "World Energy Resources: Distribution, Utilization, and Long-Term Availability." Paper delivered at the annual meeting of the American Association for the Advancement of Science, December 29, 1971.

[14] Hubbert, M. K. Chapter 8, "Energy Resources," in *Resources and Man*. W. H. Freeman, San Francisco, CA. 1969.

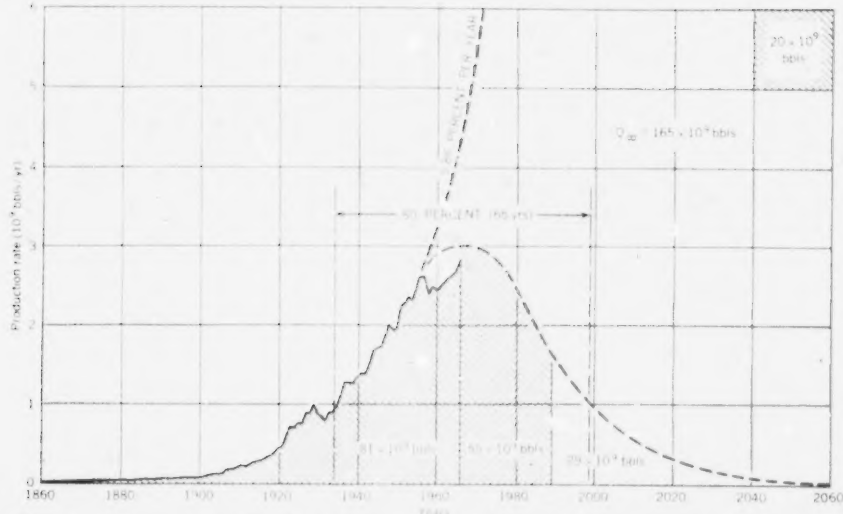


Figure 10. Use rate for U.S. oil resources. From Hubbert, M. K. Resources and Man. *P. 183. (See footnote 14.)*

The curve for U.S. oil is of particular interest. It shows that the actual rate of production from 1880 to the present does have roughly the predicted shape. If Hubbert's choice of total resources, 165 × 10^9 billion barrels, is correct, it also shows that the United States is probably now past the peak of oil production. The most important feature of a curve like this is its width, for that tells us how long a resource might be expected to last. We see that for oil, these data suggest that the total amount of oil to be produced by the United States is 165 × 10^9 billion barrels and that 80 percent of that will be produced in the 65-year period from 1934 to 1999. Thus, within our lifetime we can expect to see a radical change in the fuel mix, with petroleum losing its dominant position. The effects of this on automobile transportation will be of major importance in our automobile-centered economy.

Figure 10 for coal is consistent with the previous Figure 9. We have a great amount of coal and are just started up the slope to the peak in production. The time scale is much larger, the time to produce 80 percent of the U.S. coal is on the order of 300 to 400 years.

In combination, Figures 9, 10, and 11 give a representative view of the state of U.S. and world fossil-fuel resources. They give a qualified answer to, "How long will they last?" The answer: "Not very long," if we are talking about crude oil and natural gas; "long enough for us to find other sources," if we are talking about coal.

The answer might also have been: "Long enough for us to wreck our environment." Without much improvement in the protection we give our environment about two more doubling periods of energy consumption may be all it can take. Each doubling not only reduces the resources but, for instance, doubles the generating capacity (more plants), doubles (almost) the amount of transmission lines, doubles the coal-mining activity, doubles (unless rigid controls are implemented) the sulfur oxides and fly ash in the atmosphere, and so on.

Are There Clean Continuous Energy Sources?

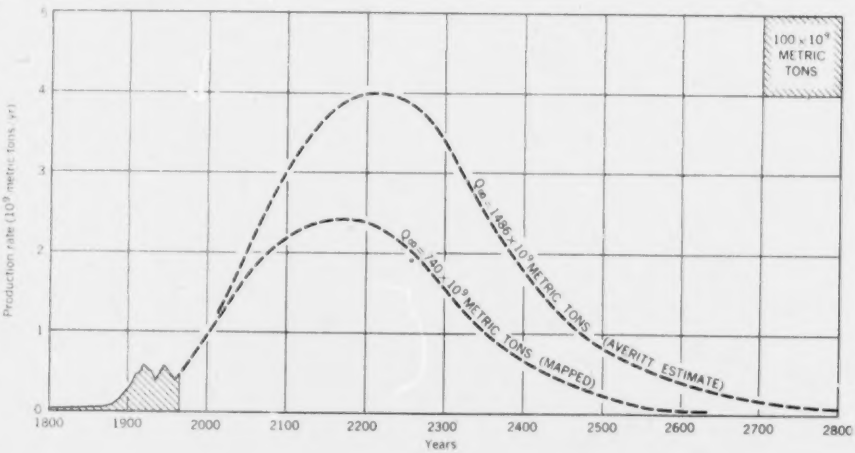
While coal may provide for our energy needs for 300 to 400 years, it won't last forever; on the scale we hope is still appropriate to mankind, the period of fossil-fuel dependency will be a short blip on the sweep of time. If we are to see a world in which all people have "energy slaves" in numbers which approach the U.S. standard, we must find some source of energy which can last for at least a few tens of thousands of years.

In Part I we cataloged the primary energy sources. Let's look at them again. The primary sources with their important components are shown in Table 4.

From Table 4 it is easy to see the necessary shape of our long-range future. Of the continuous sources only solar energy can provide energy at the level of expectation. And for solar energy, the three converters we now use—photosynthesis, hydro power, and wind power—even at maximum utilization, could just barely suffice.

If we look to the depletable sources and spend no more time discussing the fossil fuels, we see some interesting things. In the first place, we are struck by the fact that the ordinary nuclear reactor is not a long-term answer. If we successfully convert to the controversial breeder reactor, we see our first big number, and we increase our potential by a factor of 100. Finally, looking somewhat further into the future,

Figure 11. Use rate for U.S. coal resources. From Hubbert, M. K. Resources and Man. *P. 200. (See footnote 14.)*



determinedly rosy-hued, successful application of the D-D reaction in a fusion reactor could, due to the vast amounts of deuterium in the ocean, give us an essentially infinite source.

Let us now take off the rose-colored glasses and look somewhat more sceptically at the most important of these estimates. We refer the interested reader to the suggested general reading for more detailed reviews of these various topics.

Table 4. Primary energy sources with maximum power available.[a]

Continuous Sources		Maximum Power—World (*Units 10^{12} watts*)
Solar		28,000
Photosynthesis fuel		13
Hydro power		3
Wind power		0.1
Gravitational (tidal)		1.0
Geothermal		0.06
World cumulative demand 1960–2000		~ 500
World annual demand by year 2000		~ 15
Depletable sources		
Chemical (fossil fuels)		~ 1000
Nuclear		
Fission	ordinary reactor	~ 3000
	breeder reactor	~ 300,000
Fusion		$> 5 \times 10^6$

[a] Adopted from Starr, C. "Energy and Power," *Scientific American* 224: 43; September 1971.

Solar Energy

Even at the great distance of earth from sun, our share of the solar output is impressive. Solar energy, which fuels life, pours onto the earth in prodigal amount. But to harness it for the massive needs of industry is something else. Solar energy has several disadvantages. It is dilute: approximately ~18 watts/ft^2 averaged over 24 hours. It is erratic: not only is there a familiar cycle of light and darkness but less regular cloud obscuration. This latter is a serious problem since neither heat nor electricity—the most likely forms to which solar energy will be converted—can be readily stored.

There are ambitious schemes being proposed to capture and convert significant amounts of solar energy, and the budget for solar energy research is climbing from the present "hobby" level of about $50,000/year to several million. We are beginning to make a real effort to use this clean free energy more massively, but it will take decades to see results.[15]

Nuclear Energy—Fission

We have discussed in Part II some of the dangers of the ordinary nuclear reactor. This country has embarked on a program to develop the fast-breeder reactor, which uses some of the neutrons from the fissioning fuel to convert U^{238} to the reactor fuel Pu^{239}.[16] The energy arguments for this are easily seen from Table 4. What is not seen are the problems this will bring. The breeder reactor poses several. It is a new and difficult technology, running at higher temperatures (more efficient but more susceptible to cooling-water accidents), it will probably use a liquid metal heat exchanger. Most serious, however, are the dangers associated with plutonium. Creating this material in large quantities means that the half-life of waste (in which there will be some plutonium) will go from about 150 years to > 20,000 years. Can we guarantee safe storage for that long? It also means that the material for "atomic bombs" will now be created in ton lots and shipped across country and maybe across oceans. The political implications are obvious.

Nuclear Energy—Fusion

We have dreamed for 20 years of tapping the essentially unlimited resources of deuterium to fuel a D-D fusion reaction. But so far it is largely a dream. Scientifically we understand the theory, but to create a plasma of fusionable material at the 100,000,000°F we need and to hold it together for long enough to get appreciable power out, is presently beyond our means. Research in this area is being accelerated, and the optimists predict scientific feasibility by 1980 and pilot demonstration by 2000. The pessimists laugh.[17]

Fusion, if it can be tapped, offers much; not only essentially unlimited fuel, but at least hundredfold reduction in the radioactive waste problem. It will also be, we expect, free from threat of accident. There will still be heat to worry about, but the combination of cleanliness and safety may allow siting to take advantage of this heat.

Conclusion

Mankind is in the midst of a crisis of energy. It has several dimensions. On a short time scale, we are faced with a serious shortage of natural gas and, in certain places where demand has exceeded present capacity, with a shortage of electric power.

On an intermediate time scale, 30 to 60 years, we are faced with the necessity of finding a substitute for the petroleum products which now dominate the energy mix.

Finally, on a larger scale, 300 to 400 years, we are faced with the exhaustion of fossil fuels.

What can we do? Some of the answers are obvious. We can plan more carefully and further ahead. We can try to reduce energy expenditures and increase research and development support. As citizens we must demand this. We must also demand a role in the decision-making process and decide, for instance, whether we lean heavily on the breeder reactor with its dangers or rely on coal and coal products (gases and liquids).

The science teachers of this country have a vital role to play in the next few years. These decisions must be based on information, and it is the science teacher who must make sure that developing citizens have access to the necessary information devoid of bias and distortion. It is my hope that this summary, brief and sketchy as it is, can serve as a part of the foundation of that necessary effort. □

[15] For further details see Glaser, P. E. "Solar Energy—Prospects for Its Large-Scale Use." *The Science Teacher* 39: 36-39; March 1972.

[16] Seaborg, G. T., and J. L. Bloom. "Fast Breeder Reactors." *Scientific American* 223: 13; November 1970.

[17] For a review of progress toward fusion see: Auer, P. L., and R. N. Sudan. "Progress in Controlled Fusion Research." *The Science Teacher* 39: 44-50; March 1972.

Suggested General Reading

1. *Scientific American* 224; September 1971. The issue is devoted entirely to energy.
2. "The Energy Crisis." *Bulletin of the Atomic Scientists* 27; September and October 1971. Two issues on energy.
3. *The Science Teacher* 39; March 1972. Five articles on energy.
4. Romer, R. H. "Energy-Resources, Production and Environmental Effects." A Resource Letter of the American Association of Physics Teachers. *American Journal of Physics* 40: 805; June 1972.

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I. BASIC GENERAL REFERENCES

1. Energy in the United States: Sources, Uses and Policy Issues.
2. "Energy and Power."
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4. The Economy, Energy and the Environment.
5. Environment, Power and Society.
6. Energy in the Perspective of Geography.

II. ENERGY POLICY

1. U.S. Energy Policies: An Agenda for Research.
2. Petroleum Conservation in the United States: An Economic Analysis.
3. "Limits to the Use of Energy."

III. BASIC REFERENCES: ELECTRIC POWER

1. Environmental Effects of Producing Electric Power.
2. Selected Materials on Environmental Effects of Producing Electric Power.
3. Environmental Cost of Electric Power.
4. Power Generation and Environmental Change.
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IV. NUCLEAR POWER

1. A Citizens' Guide to Nuclear Power.
2. Nuclear Power and the Public.
3. "Social Institutions and Nuclear Energy."
4. "Fast Breeder Reactors."
5. "Nuclear Energy and The Environment."

V. FOSSIL FUELS

1. "Clean Power From Coal."
2. "Clean Power From Dirty Fuels."

VI. ENERGY RESOURCES

1. Energy Resources.
2. "Energy: The Saga of the Fossil Fuels."
3. "When the Well Runs Dry."

VII. FUTURE SOURCES OF ENERGY

1. "Controlled Fusion: Status and Outlook."
2. "Fusion Power."
3. "Power From The Sun: Its Future."
4. "Power From The Earth."
5. "Geothermal Power."

VIII. DATA

1. The 1970 National Power Survey.
2. Patterns of Energy Consumption in the United States.
3. Energy in the American Economy, 1850-1975.
4. Energy in the United States, 1960-1985.
5. The Nuclear Industry 1970.
6. The Nuclear Industry 1971.
7. Energy in the World Economy: A Statistical Review of Trends in Output, Trade, and Consumption Since 1925.
8. The 1969 Statistical Yearbook.

IX. STUDENT READING

1. The Next Hundred Years.
2. The Limits to Growth.
3. Energy.
4. Energy.
5. The Closing Circle.
6. The Concept of Energy Simply Explained.
7. Night Comes to the Cumberlands.
8. The Careless Atom.
9. Direct Use of the Sun's Energy.

I. BASIC GENERAL REFERENCES

1. ENERGY IN THE UNITED STATES: SOURCES, USES AND POLICY ISSUES

Authors: H. H. Landsberg and S. H. Schurr, Resources for the Future, Inc.

Publisher: Random House, New York, 1967. (231 pp.; $ 3.50)

Point of View: Presentation of Information. Part II documents the need for more energy planning.

Level: Intended to be popular, non-technical; many tables and graphs.

Summary: This is perhaps the most coherent source on the entire energy picture. It is essentially a non-technical summary of two earlier reports on Resources for the Future studies: Energy in the American Economy, 1850-1975 by Schurr and Nelschert (published 1960) and Resources in America's Future by Landsberg, Fischman, and Fischer (published 1963).

Part I, "History and Prospects" comprises seven chapters. The first of these provides an overview of the role of energy in the economy and briefly summarizes the sources of supply and the sectors of consumption. A fairly detailed discussion of the methods and costs of transporting energy in different forms is provided along with a survey of the "energy industries" (the magnitude of their investments, etc.).

The second chapter surveys the changes over time and the present state of the sources of supply and of the sectors of consumption. Chapter 3 is concerned with predicting future demand and presents much useful data on expected growth and change in energy use in the various sectors of the economy. Chapter 4 deals with the fossil fuel resources and gives not only a careful estimate of the extent of reserves but a helpful discussion of how such estimates are made. Chapter 5 surveys the possibilities of energy from new sources and processes. A historical resumé of nuclear fission is provided, along with a summary of the present situation as to the economic and political factors involved. Other new sources or processes are treated very superficially, i.e. fusion, direct conversion (with a useful "energy conversion matrix" that represents the various relationships, and brief discussions of thermoelectric generation, thermionic conversion, fuel cells, and magnetohydrodynamics (MHD)) coal conversion, new sources such as oil shale and sands, and finally a quick look at sun and wind, geothermal and tidal energy. Chapter 6 then concentrates on electrical energy, discussing it from a geographic and economic point of view. Finally, Chapter 7 summarizes Part I under the title "The Outlook for Adequacy," and raises some of the policy questions to be discussed in the next section.

In Part II, "Public and Policy Issues," the issues of regulation, imports, taxation, etc. are thoroughly discussed. The authors not only try to sort out the effects of both public and private policies but make some recommendations of their own. The major missing component is environmental cost; there is almost no discussion of the environmental problems associated with the various forms of energy production and consumption.

2. ENERGY AND POWER

Authors: Several. This is a single topic issue with eleven contributing authors.

Publisher: Scientific American 224, September 1971. (Published as Energy and Power, Scientific American Books, W. H. Freeman, San Francisco, 1971.) (Paperback $ 3.25)

Point of View: Comprehensive treatment, objective, with very little attention to environmental consideration.

Level: Popular treatment with data presented by graphs and charts.

2. ENERGY AND POWER (cont'd.)

Summary: There are eleven articles in this single theme issue on various aspects of the energy picture. The lead article, "Energy and Power" by Chauncey Starr, is an overview of the entire energy picture giving some of the historical interaction between the evolution of power sources and society and current data on consumption and supply. There is a brief reference to environmental effects, chiefly air and thermal pollution. There is also a useful section on long-range planning which contrasts the "power problem" in developed and undeveloped countries, looks at some of the controlling factors which influence energy policy, and considers the "benefit-risk" questions related to energy use and environmental damage.

The second article, "Energy in the Universe" by Freeman Dyson, takes a truely "universal" view of energy and energy flow. Energy is looked at from the thermodynamic standpoint; the various forms of energy in the universe are considered from the point of view of entropy. There is also a discussion of why the gravitational energy of the universe is not already degraded. This article is somewhat more technical than the others.

In "The Energy Resources of the Earth" M. King Hubbert provides an input-output approach to the earth's energy. The problems of estimation of fossil fuels and of other resources, chiefly solar conversion, fission and fusion are carefully dealt with. The article is rich in data.

"The Flow of Energy in the Biosphere" by David M. Gates and the following two articles, "The Flow of Energy in a Hunting Society" by William B. Kemp and "The Flow of Energy in an Agricultural Society" by Roy A. Rappaport, present a background against which to measure the energy crises facing industrialized societies. The Gates article provides quantitative data on the various energy exchanges in the biosphere while the other two provide fascinating quantitative and qualitative data on energy input/output for two primitive groups.

"The Flow of Energy in an Industrial Society" by Earl Cook deals chiefly with the U.S. energy consumption; with changes over the past hundred or so years, with comparative efficiencies and, briefly, with future possibilities. A major feature is a detailed input/output flow diagram of U.S. energy use.

"The Conversion of Energy" by Claude M. Summers describes the various important energy conversions and the efficiencies of these conversions. It reviews important or potentially important conversion devices, particularly solar and nuclear, and ends with a thorough exploration of growth curves and the effects of changes in their parameters.

"The Economic Geography of Energy" by Daniel Luten deals mainly with the transportation of energy, from resource location to the point of conversion or consumption, and with storage problems.

"Energy and Information" by Myron Tribus and Edward McIrwine is a technical treatment of the relationship between these two quantities. It describes the strong connections between uncertainty in information and "unavailability" of energy and has some interesting data on the energy cost per bit of information for various forms of communicating.

"Decision Making in the Production of Power" by Milton Katz describes and illustrates the ways in which "technological assessment" can help resolve the conflicts arising from the application of "enterprise criteria," efficiency, production costs, etc. and "societal criteria," environmental damage, etc.

3. THE ENERGY CRISIS : PARTS I - III

Author: Several. This is a compilation of articles by 29 writers.

Publisher: Science and Public Affairs, Bulletin of the Atomic Scientists 27, Nos. 7-9, September, October, November 1971. (Published in book form as The Energy Crisis and available from: Circulation Manager, Bulletin of the Atomic Scientists, 1020-1024 E. 58th Street, Chicago, Ill. 60637.) (Paperback $ 2.95)

Point of View: An attempt has been made to present a balanced viewpoint over all.

Level: Varies from article to article, but non-technical for the most part.

Summary: This three-part discussion of the "Energy Crisis" provides not only a most comprehensive summary but also incorporates a useful range of view points on controversial topics such as nuclear energy. The three issues present 26 articles on energy. Nuclear energy, its benefits and risks, is the central issue in fourteen of these. There are, in addition, articles on alternative power sources - solar, geothermal and fusion - on energy policy alternatives and considerations and miscellaneous articles on citizen protest and on energy policies and programs in the USSR and Yugoslavia.

Part I, the September issue, deals with "The Radiation Controversy." The pro-nuclear power point of view has the first and last word. Bernard Spinrad of the Argonne National Laboratories in his lead article "America's Energy Crisis: Reality or Hysteria" discusses the fuel crisis as "artificial" and caused largely by unrealistic emission standards. The "four issues of nuclear power," thermal pollution, radioactive pollution, waste disposal, and the danger of accidents, are then considered. He dismisses the first two of these quickly and the last two more carefully. His overall conclusion is that reactors are safe and necessary. He does recommend that the duty of regulating nuclear safety be lodged in some agency other than the AEC.

In the final article "On Misunderstanding the Atom," Glenn Seaborg, writing as AEC Chairman, makes an even stronger case for nuclear energy. The article is organized around the following major themes: 1) More energy will be needed as the population grows, as per capita use increases and as we try for a "technological fix" of our environmental problems; 2) The demand for electrical energy will continue to increase; 3) Only nuclear energy is a deep enough resource to meet these needs; 4) the burning of fossil fuels contributes seriously to the environmental problem and depletes an important raw material. Seaborg deals briefly with current criticism of nuclear energy but ends with predictions that it will prove to be the dominant and least injurious of all the future sources of energy.

Following Spinrad's article is a valuable technical resumé by MIT Nuclear Engineer Manson Benedict on fission reactors, both "first generation" reactors, and the "second generation" breeder reactors. It contains useful schematic drawings and data on U.S. and foreign reactors.

The central six articles of Part I deal more narrowly with radiation dangers. Arthur Tamplin, John Gofman, and Donald Geesaman from the AEC biomedical division at Livermore put forward their well-aired and controversial predictions as to the threats to human health of a conversion to nuclear energy. The Tamplin article summarizes the criticism he and Gofman have made in the past of the AEC approach to nuclear energy. Gofman takes a broader view of technological problems and proposes a scientific adversary approach to them. Geesaman's article focuses on the breeder reactors and provides a useful summary of some of the hazards, particularly that of greatly expanded production of Plutonium, which they present.

The reader who is confused by the pro-con views of nuclear radiation hazards is assisted in two articles by internationally distinguished authorities on radiation effects. J. Rotblat, currently of the medical college of St. Bartholomew's Hospital, London, writes with Patricia Lindop on "Radiation Pollution of the Environment" providing a careful background on what is known and un-

3. THE ENERGY CRISIS (cont'd.)

known in this area and adding a balanced view of the "radiation controversy." Joshua Lederberg, Stanford University geneticist, also briefly summarizes the background knowledge and attempts the very important cost-benefit analysis which is necessary for decision making.

While the articles briefly summarized above deal chiefly with aspects of the radiation controversy, there are further contributions in the three issues to the broader question of nuclear energy. Rolf Eliassen's article in Part I on "Power Generation and the Environment" deals in depth with the problem of thermal pollution and power plant siting and suggests some novel ways out of some of our current difficulties - combining strip mining with waste disposal or "mine-mouth power plants" with new cities.

The nuclear energy picture is also examined in Part III, the November issue, from the British, Soviet, and Yugoslavian point of view. The radiation controversy itself is examined from a Canadian nuclear establishment point of view and in a different style by the presentation "The Palisades Protest: A Pattern of Citizen Intervention."

With Part I and Part III concerned largely with the nuclear controversy, the broader aspects of the "energy crisis," economical policy making, etc. are dealt with in five articles in Part II. Victor Parsegian, a physicist at Rensselear Polytechnic Institut, presents his overview of the energy crisis under the title "New Goals for Atomic Energy." S. David Freeman, writing as Assistant Director for Energy and Environment of the OST, takes the much needed and unique - at least in these three issues - approach "Toward a Policy of Energy Conservation." He analyzes the soaring growth of energy consumption, and its effects and causes - particularly the promotional bias of the energy industries. In what is to some extent a companion article, Bruce Netschert, an energy economist, examines the monopoly trends - the growth of the "energy companies " - with data on the energy holdings of major oil companies and with some warnings as to the difficulties they pose for a national energy policy.

There are two other articles in this section on policy, "Outlook for Energy in the United States" by John D. Emerson, an energy economist for the Chase National Bank, and "Energy Policy-Making" by Irvin L. White, a political scientist who is assistant director of the Science and Public Policy Program of the University of Oklahoma. The first of these, a short article, assumes the continuing growth and points out some of the reasons, from the industrial viewpoint, of the present crisis. Emerson particularly underlines the role of investment, the time lag for change and the effects of rates and imports.

The last article is a thoughtful and comprehensive summary of the dimensions of the energy crisis, the causes and some ways to overcome it. White examines the degree of responsibility of the energy companies and of government for the present state and makes some recommendations toward mitigation of the difficulties.

The third category of articles which occupies the last half of Part II in the second issue is "Technical Alternatives." There are two articles on solar power, the first of which, by Norman Ford and Joseph Kane (physicists at the University of Massachusetts) contains a brief look at other technologies but concentrates on a proposal to use the Fresnel lens to collect and focus the sun's energy and to store it by thermal dissociation of water. The bulk of the article is a detailed treatment of the techniques and their costs.

The second article by Aden and Marjorie Meinel makes the case for their now rather well-known proposal for "solar power farms" in the southwestern deserts where solar energy is collected by one-way plastic windows, transported by liquid metal heat exchanges, stored as heat and used in traditional steam generating plants. The Meinel article gives much attention to the environmental impact and to the impact on the sociology and economics of the region.

The third article in this section, "Underground Nuclear Power Plants," examines the technological and economic implications. The next two articles are on fusion.

3. THE ENERGY CRISIS (cont'd.)

"Fusion Power, the Uncertain Certainty" by Richard Post of Livermore Radiation Laboratory surveys the difficulties (the confinement problem, the magnetic dilemma, stabilization principles) describes the most promising present approaches (complete with helpful drawings), and ends with some predictions (application by 1980). There is little discussion of actual application or of environmental effect.

The other contributions to the fusion story are "Notes on the Fourth Conference on Plasma Physics and Nuclear Fusion Research at Madison, Wisc., June 1971."

These notes consist of a brief collection of opinions from various fusion experts and a somewhat longer interview with L.A. Artsimovitch of the USSR.

Geothermal energy, the last of the technical alternatives considered, is discussed by Robert Rex, a geophysicist at the University of California - Riverside. He describes existing efforts to extract geothermal energy, proposes further directions of development and provides some data on costs and total reserves.

4. THE ECONOMY, ENERGY AND THE ENVIRONMENT

Author: A background study prepared for the use of the Joint Economic Committee, Congress of the U.S., by the Environmental Policy Division, Legislative Reference Service.

Publisher: U.S. Government Printing Office, Sept. 1, 1970. (131 pp.; 55 cents)

Point of View: Inclusive. The study surveys the existing literature on the technical aspects of electric power production, the supply of the various fuels used in the production of electricity, and the environmental consequences of energy conversion.

Level: Popular.

Summary: The first section of this report, "Energy: An Overview" provides a quick summary of the major trends in U.S. energy consumption, briefly examines the implications of exponential growth, particularly in the electric industry, and reviews the current findings as to existing and potential supplies of various fuels. The list of some forty "underlying assumptions" upon which such projections are based provides a quick overview of some of the major issues in the energy question.

In the next section, "Is there an energy gap?" the various "brownouts" and "blackouts" that occurred between 1968 and 1970 are reviewed and public opposition to the construction of power plants and, potentially, to the increased proliferation of transmission lines, is examined.

"Energy for the Electric Industry," the third and most extensive section, deals with supply-demand forecasts and their fallibilities and with the technology and availability associated with each of several fuels: coal (including a treatment of strip mining technology and a projection for its increase), oil (off-shore drilling is briefly examined), natural gas and nuclear fuels (including a look into the environmental effects of uranium mining).

"The Electric Industry" is the subject of the next section and the focus is on the economics of utilities, their "capital intensive" nature, the changing sources of capital and predictions for expansion and the accompanying need for construction of new facilities. Consideration is given to the pricing of electricity and to the trends toward very large power plants.

In the final section, "Environmental Effects of Generating Electricity and their Economic Implications," the principal wastes of the electric industry are identified, their effects briefly described and current wast regulations and present technology for control summarized. Cost information is also provided.

5. ENVIRONMENT, POWER AND SOCIETY

Author: Howard T. Odum, Graduate Research Professor, Department of Environmental Engineering, University of Florida - Gainesville.

Publisher: Wiley-Interscience (New York: John Wiley and Sons, Inc.) 1971. (331 pp.; $ 5.95)

Point of View: Objective, in so far as all the processes analyzed are looked at in the same light, from the energy viewpoint.

Level: Technical, but the mathematical level is not difficult. It is useful as a reference work on the basis of its quantitative flow diagrams alone.

Summary: This is a somewhat strange and difficult book whose close study is quite rewarding. It is not a book on the energy crisis as such, but rather one which examines the structure and function of nature and society from the point of view of energy. Odum applies the "systems approach" to a wide spectrum of systems ranging from "terrestrial microsystems," such as the terrarium to the planet itself and from photosynthesis to religion.

The book begins with careful definitions of work, power, and energy from the broader ecological point of view which complements and extends the physical science definitions. There is a very useful chapter, "Power in Ecological Systems," which is rich in data on power flows in nature.

The first five chapters are probably the most useful to a course on energy dealing with energy flows of conventional types - solar, geothermal, etc. There is a unique treatment of the relation of work, potential energy and energy loss, of reversible and irreversible processes and a categorization and discussion of "storage work" (work involved in storing energy), "processing work" (work done in arranging matter), and "accelerating work."

The last chapters of the book apply the energy flow diagrams to economics, politics and religion. These applications are much more difficult to follow, but are challenging and provide on the way much insight into the systems which characterize the scope of these disciplines.

Odum has written a truely interdisciplinary book and displays an impressive range of knowledge in many fields. It is difficult to judge whether he has succeeded in his larger purpose of demonstrating the wide applicability of the energy system analysis to society at large. It is clear, however, that the impressive collection of data and examples which he has mustered for his purpose is itself a significant contribution to the understanding of energy.

6. ENERGY IN THE PERSPECTIVE OF GEOGRAPHY

Author: Nathaniel B. Guyol, Geographer and Consulting Economist, San Rafael, California.

Publisher: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1971. (156 pp.; $ 2.95)

Point of View: Presentation of Information; textbook.

Level: This is one of the Prentice-Hall "Foundations of Economic Geography" series. It is written as a text book but can be understood without a background in either economics or geography.

b. ENERGY IN THE PERSPECTIVE OF GEOGRAPHY (cont'd.)

Summary: This economic-geography text covers somewhat the same material as reference I-1. It is intended to investigate the factors and relationships that influence the world's energy economy. The first two chapters provide a useful data-rich review of the nature, uses, and sources of energy and of the world energy picture. The next two chapters are designed to instruct the reader in the techniques of data gathering and analyzes "energy accounting," but in the process provide useful, concise definitions both of the many different forms of fuel and their importance and of the different sectors of the economy and the forms of energy identified with them.

These are followed by a brief discussion of factors affecting the efficiency of energy use and some tabular data to this end, then four chapters dealing in detail with energy demand in transport and agriculture, the domestic sector, industry, and in electric power. The last two chapters show how to compute percentages, rates of change, etc., and investigate the helpfulness of energy measurements as indicators of various economic trends in different countries. There are two appendices, one providing conversion tables for fuels from tons of coal to barrels of ore, BTU's, etc., and one presenting a table for compound interest calculations.

Taken by itself this text does not provide depth of understanding of energy from a physical science point of view, but it does provide a very helpful sidelight to such an approach and will be particularly helpful in understanding the sources and style of presentation of the kind of statistical data which delineates the energy crisis.

II. ENERGY POLICY

1. U.S. ENERGY POLICIES: AN AGENDA FOR RESEARCH

Author: The staff of Resources for the Future (RFF), "a non-profit corporation for research and education in the development, conservation and use of natural resources".

Publisher: Johns Hopkins Press, Baltimore, Md., 1968. (152 pp.; $ 4.00)

Point of View: There is no U.S. "energy policy" as such. "The policies relating to each industry have arisen out of problems encountered in that industry, and have been shaped by a variety of technical, economic and idealogical factors in changing political situations."

Level: Non-technical. This is one of a set of energy studies which RFF prepared to "enlarge understanding" of the energy industries within and outside government and to provide background for policy decisions.

Summary: Prepared by RFF for the Office of Science and Technology, this study presents a description of those energy policy questions which RFF believes would profit from study and analysis. It is, therefore, an agenda for research and is not, in itself, a study that offers energy policy recommendations.

There are two components to the study: recommendations for future research into energy problems and a concise description and analysis of the policy issues facing government and the energy industries.

Chapter I, "A General View of the Energy Industries," deals with public involvement with the energy industries, postwar growth and consumption of energy, foreign trade, the dimensions of the energy industry and future energy requirements.

This discussion is followed by six chapters, each dealing with a separate energy source: oil, natural gas, coal, electricity, nuclear energy, and shale oil. The structure of the industry and the regulations associated with each fuel are presented along with details of the economics involved and an analysis of the industry's policies.

The final chapter, "Toward a coordinated approach to Energy Problems," contains a discussion of the quantitative framework for assessing supply and demand (statistical projections, resources vs reserves, industry costs and supply functions) and a concluding section on "Energy Policies as Evaluated from Several Vantage Points" (cost efficiency, incentives to private industry, energy R & D, national security, etc). A number of useful tables are presented throughout the text.

2. PETROLEUM CONSERVATION IN THE UNITED STATES: AN ECONOMIC ANALYSIS

Author: Stephen L. McDonald, Professor of Economics, University of Texas at Austin.

Publisher: Johns Hopkins Press, Baltimore, Md. (Resources for the Future) 1971. (279 pp.; $ 10.00)

Level: Non-technical but quantitative in parts. Addressed to "oilmen, regulators, legislators, students and conscientious citizens generally." Contains a number of useful tables.

2. PETROLEUM CONSERVATION IN THE U.S. (cont'd.)

Point of View: While noting that the present conservation system is better than no regulations at all, McDonald points out serious defects in the system's control of economic wastes and suggests that "compulsory unitization (i.e., that all petroleum reservoirs be developed and operated as units) is the route to efficient exploration and production of oil."

Summary: The main concern of this study is the economic efficiency with which we exploit our petroleum resources and how this relates not only to "quality of life" questions, but to the determination of the size and growth of the domestic petroleum industry.

The study is divided into four parts. Part I, "The Setting of the Problem," provides a factual discussion of the natural occurance, discovery, production and marketing of petroleum, stressing "the technical and institutional peculiarities which give rise to conservation and related problems." The problems with which regulation attempts to deal are identified and a historical survey of regulations is presented. In Part II, "Economics of Petroleum Conservation," the role of conservation in the general economic process and the meaning of economic efficiency are discussed. Optimum time-distribution of use is discussed at some length, as is the interaction between optimum rates of production and exploration. The final chapter in this section deals with demand for, supply and price of crude oil. Part III, "Evaluation of Conservation Regulation" consists of four chapters: "The Concept of Prohibited Waste," "Control of External Damages," "Control of Production and Well Spacing," and "Unitization and Unit Operation of Reservoirs." The final section, "For the Future," consists of a single chapter of proposals for modifying the present regulatory system.

3. LIMITS TO THE USE OF ENERGY

Authors: A. M. Weinberg, Director of the Oak Ridge National Laboratory, and R. P. Hammond, Director of the ORNL Nuclear Desalination Program.

Publisher: American Scientist 58: 412-417, July-August, 1970.

Level: Popular, non-technical.

Point of View: Exceedingly optimistic and pro-nuclear.

Summary: The authors state their thesis in three propositions:

1) Energy is convertible into most of the other requirements of life.
2) The energy available in nuclear sources is essentially inexhaustible.
3) Whatever the limits to man's utilization of energy . . . they come not from a absolute limit on the total fuel in the earth's crust but rather from environmental side effects . . . The limit . . . is probably very large.

This article serves, therefore, as a balance to articles emphasizing energy resource shortages and accompanying environmental problems.

First, estimates of the costs of certain key conversions, i.e. salt to fresh water and water to hydrogen fuel, are provided. The authors then make some crude estimates of future per capita needs and arrive at the figure of 600×10^6 BTU, double the present U.S. figure. With that figure as a target they examine the breeder reactions (the "catalytic burning of nuclear fuels") and find that, for instance, "the Conway granites should provide nuclear fuel for the whole world for about 200 years."

3. LIMITS TO THE USE OF ENERGY (cont'd.)

After identifying such low concentration sources of Uranium the authors briefly discuss the environmental problems of thermal and radioactive pollution, finding "energy parks" on the ocean and salt mine storage the respective solutions.

This brief article puts forward many of the optimistic views of the proreactor lobby. It is therefore useful not only for balance but as a study document for social and other scientists to examine and criticize.

CROSS REFERENCES

4. "Public Policy Issues," Chapter 8 in Energy in the United States: Sources, Uses and Policy Issues. (See Reference I-1).

5. "Energy and Power," Chauncey Starr, Scientific American 224: 36-49. (See Reference I-2).

6. "Decision Making in the Production of Power," Milton Katz, Scientific American 224: 191-200. (See Reference I-2).

7. "The Energy Crisis: Part II," Science and Public Affairs: Bulletin of the Atomic Scientists, October 1971. (See Reference I-3).

8. "Environmental Science and Public Policy," James A. Fay in Power Generation and Environmental Change, ed. David A. Berkowitz and A. M. Squires (Cambridge: MIT Press) 1971, pp. 3-7. (See Reference III-4).

III. BASIC REFERENCES: ELECTRIC POWER

1. ENVIRONMENTAL EFFECTS OF PRODUCING ELECTRIC POWER

(PART I, PART II, VOL. I AND PART II, VOL. II)

Author: Hearings before the Joint Committee on Atomic Energy, Congress of the United States, 91st Congress, 1st and 2nd Session, 1969-70.

Publisher: U.S. Government Printing Office, 1970. (5677 pp.; $ 10.75)

Point of View: Balanced. An attempt has been made to gather testimony from individuals having widely different viewpoints.

Level: Varies, depending on who is testifying, but for the most part understandable to a non-technical reader.

Summary: These three volumes of hearing materials, taken together with the background report reviewed below (see Ref. III-2), are frequently cited as the most valuable starting point for anyone seeking an overview of the energy-environment controversy.

Part I contains the policy statements and testimony of representatives from those government agencies having responsibility in the area of environmental effects of electric power production: AEC, FPC, HEW, Department of Interior, OST, etc.

Part II reports testimony from representatives of state governments (the selection dealing with Minnesota is particularly interesting), environmental organizations, the scientific community (including many pages of Gofman-Tamplin testimony) and the general public.

Taken as a whole, this report, though tedious and repetitious at times, provides not only a valuable summary of the issues involved but a good close-hand look at the interactions between government and the public.

2. SELECTED MATERIALS ON ENVIRONMENTAL EFFECTS OF PRODUCING ELECTRIC POWER

Author: Prepared by the Staff of the Joint Committee on Atomic Energy, Congress of the United States.

Publisher: U.S. Government Printing Office, August 1969. (553 pp.; $ 2.50)

Point of View: Most of the documents included are from government agencies: The Atomic Energy Commission, Federal Power Commission, and the Office of Science and Technology.

Level: Non-technical.

Summary: This is a good collection of background documents consolidated by the JCAE in anticipation of later committee hearings (see Ref. III-1). Two particularly important articles are excerpted here in their entirety: "Considerations Affecting Steam Power Plant Site Selection" (sponsored by the Energy Policy Staff, Office of Science and Technology), and "Problems in Disposal of Waste Heat from Steam-Electric Plants" (FPC Staff Study, 1969). Selections from additional papers, reports, remarks and correspondence deal with various aspects of the fossil-nuclear power controversy. "Standards of Protection Against Radiation," reprinted from the Code of Federal Regulations, is also available here in its entirety.

3. ENVIRONMENTAL COST OF ELECTRIC POWER

Author: Dean E. Abrahamson, Assoc. Prof. of Anatomy and Laboratory Medicine, University of Minnesota, President, Minnesota Committee for Environmental Information and Vice-Chairman, Scientists Institute for Public Information (SIPI) Board of Directors.

Publisher: A Scientists Institute for Public Information Workbook, published by SIPI, (30 East 68th Street, New York, N.Y. 10021) 1970. (36 pp.; $ 1.00)

Point of View: ". . . power generation on the massive scale which Americans have learned to take for granted is a large contributor to the degradation of the environment."

Level: Non-technical. This is one of a series of workbooks addressed to those "newly involved with the social issues engendered by the environmental crisis."

Summary: An introduction by Barry Commoner, a 29-page essay and a suggested reading list comprise this brief but useful workbook. "Power Per Person" is the first problem addressed and Abrahamson structures the argument that it is the increase in per capita use of energy and not just population increase which threatens the environment.

In "How Much Does it Really Cost?" the complexities of cost-accounting for power plants are introduced. A comparison between fossil and nuclear plants (illustrated with a two-page flow chart) is drawn on the basis of four similarities: dependence on steam-electric generation plants, shared problems of thermal and water pollution and use of land for power transmission. A brief explanation of a steam-generating station and of the efficiency of a fossil fuel plant versus a nuclear plant introduces the topic of thermal pollution, its causes, effects, possible controls and their costs. Associated problems of chemical pollution and transmission lines are briefly mentioned.

Unique features of nuclear power plants, particularly their radiation hazards, and those of fossil fuel plants, with emphasis on air pollution and effects of coal mining, are described. A few paragraphs are given to the problems of hydroelectric power through the example of Egypt's Aswan Dam. This section then concludes with a look at potential energy resources, from known supplies to future possibilities such as solar energy, fusion, MHD, CTR and Breeder Reactors. Factors which ideally are considered in the selection of steam electric plant sites are listed at the end of this section.

In the final section, "Why More Power?" the growth rate and high per-capita power consumption in the U.S. is set forth as a continuing threat to the environment. A much wider look at the activities which create this accelerating demand for electric power and a detailed evaluation of the cost of providing this power is called for. Unrestrained electric power growth is seen as an assumption which badly needs serious challenge.

4. POWER GENERATION AND ENVIRONMENTAL CHANGE

Author: Edited by David A. Berkowitz (currently on leave from the MITRE Corporation to join the faculty of the University of South Pacific in Suva, Fiji, under the auspices of the Peace Corps) and Arthur M. Squires (Chairman of the Department of Chemical Engineering, City College of the City University of New York.)

4. POWER GENERATION AND ENVIRONMENTAL CHANGE (cont'd.)

Publisher: The MIT Press, Cambridge, Mass., 1971. (440 pp.; $ 16.95)

Point of View: Balanced. This is a report of the Symposium of the Committee on Environmental Alteration, American Association for the Advancement of Science, December 28, 1969. It is based on the belief that "man's desire for power must be reconciled with the needs of his environment."

Level: Fairly technical. Most of the papers in this collection are addressed to a scientific audience.

Summary: The 23 papers which make up this volume are concerned with the effects that power generation has had on the land, the water, the air and the biosphere. The technological means available for abatement and control of damaging environmental effects are reviewed and power generation techniques that could prove more compatible with the environment are described.

Section I, "Power, Man and Environment" contains three papers: "Environmental Science and Public Policy," a call for finding the means to incorporate scientific studies into the forming of public policy; "Power Generation and Human Ecology," which deals briefly with the relationship between the low cost of power and the problems of pollution; and "Future Needs for Power from Coal," a paper by a Commonwealth Edison Official, which touches briefly on the power industry's current and future commitment to coal, the implications of that commitment in light of associated air pollution problems, and the need for the coal producers themselves to take more initiative in pollution technology R & D.

Section II, "Nuclear Power and Radionucleides in the Environment," consists of six fairly technical papers on nuclear reactors and public health and safety. Contributing authors include Merril Eisenbud ("Nuclear Power Reactors and the Radioactive Environment"), Arthur Tamplin ("Nuclear Reactors and the Public Health and Safety"), and the Study Panel on Nuclear Power Plants of the Maryland Academy of Sciences ("Radiation Dose Limits"). The editors have included a section, "Other Views on Public Health and Safety," which reviews and discusses the most controversial points raised in Tamplin's paper in an attempt to present a "balanced viewpoint" on the subject of radiation doses.

Hydroelectric Power is the subject of the third section, which consists of two papers, one a rather lengthy (25 pages) examination of the "Ecological Effects of Hydroelectric Bans" and one, "Pumped Storage Hydroelectric Projects," which deals with the technology and environmental aspects of this technique for meeting peak-demand power needs.

Section IV, "Fossil-Fuel Power," contains seven papers, three dealing with clean power from coal (see Ref. V-1) and sulfur in residual fuel oil, and with environmental aspects of coal mining (see Ref. III-5), and four which treat various atmospheric chemistry topics which bear on air pollutants associated with fossil fuels.

"Waste Heat" is considered in the final section and papers are presented on "Environmental Quality and the Economics of Cooling," "Impact of Waste Heat on Aquatic Ecology," a good overview paper entitled "Thermal Effects - A Potential Problem in Perspective," "Alternative Technologies for Discharging Waste Heat," and "Comments on the Use and Abuse of Energy in the American Economy," a brief treatment of power growth rates, and the need to establish "a national energy policy on a broad front."

Brief bibliographies and summary sections are included at the end of each paper and answers to questions posed by symposium participants are included at the end of some sections.

5. ELECTRICITY DEMAND GROWTH AND THE ENERGY CRISIS

Authors: D. Chapman and T. Mount, Cornell University, T. Tynell, Oak Ridge National Laboratory.

Publisher: Science 178: 703-708, 17 Nov. 1972.

Point of View: Objective analysis of demand growth.

Level: Technical; data and methods of computation are presented.

Summary: These authors have made a careful study of the effects of certain causative factors on the growth in the demand for electric power. Based on other studies they have selected as the important factors, population, income, the price of electricity and of natural gas. They have tested the effects on the demand growth of various projected changes in these factors. The interesting and important result of this study is their conclusion that, while the usual method of projecting demand growth worked in the 1960's and may be expected to give reliable results until about 1975, its use would probably seriously overestimate needs of the 1980's. The authors make the further useful suggestion that this new method should be applied to other energy projections.

CROSS - REFERENCE

6. "Energy for the Electric Industry" and "The Electric Industry" in The Economy, Energy and the Environment, Joint Economic Committee (Washington: U.S. Government Printing Office), 1970. (See Ref. I-4).

IV. NUCLEAR POWER

1. A CITIZENS' GUIDE TO NUCLEAR POWER

Author: Ralph E. Lapp, physicist-author of numerous articles on energy and nuclear power.

Publisher: The New Republic, Washington, D.C., 1971. (55 pp.; $ 0.75)

Point of View: Lapp's overall thesis is that there needs to be more public information and more public involvement in the whole area of nuclear power.

Level: Popular. Originally printed as a series of four articles in The New Republic magazine.

Summary: The overall thrust of the four essays in this pamphlet is a call for the establishment of a long-range national energy policy which would take into account such problems as the future "fuel mix," proper siting of power plants, thermal protection for waterways, reliable long-distance power transmission, the financing of energy R & D and the conservation of national energy resources.

In Part I, "Where will we get the Energy?" Lapp contrasts the exponential growth of U.S. energy demand with the diminishing fossil fuel supply, briefly discusses breeder reactor economics and safety considerations and raises the issue of abating our national appetite for Kilowatts.

Part II, "Safety," is put forward as the most pressing topic and Lapp provides a particularly critical view of siting nuclear power plants in high-density population areas and of leaving the matter of safety entirely to the AEC.

In Part III, "Power and Hot Water," the problems of deterring effects of thermal pollution are discussed and the Calvert Cliffs controversy is briefly examined. In the final section, "Radiation Risks," Lapp provides a good popular-level treatment of the meaning of AEC radiation standards and some of the controversy, particularly the Gofman-Tamplin arguments, which have surrounded them.

All in all, a very readable, popular-level introduction to some of the major issues in the nuclear power controversy and, more importantly, one of the few to encourage more public information and more public involvement in the area of nuclear power.

2. NUCLEAR POWER AND THE PUBLIC

Author: Edited by Harry Foreman, M.D., Director of the Center for Population Studies at the University of Minnesota.

Publisher: University of Minnesota Press, Minneapolis, 1970. (273 pp.; $ 9.00)

Point of View: Inclusive. The intention here is to provide a neutral forum for the discussion of issues central to the nuclear power controversy.

Level: Varies from paper to paper. Those dealing with technical subjects, such as effects of thermal pollution on aquatic life, radiation regulation, etc. are written on a very sophisticated level. Others are addressed to a lay audience.

Summary: The fourteen papers which comprise this volume are based on presentations and discussions from a symposium on "Nuclear Power and the Public," held at the University of Minnesota on October 10 and 11, 1969, in response to the controversy over the Monticello power plant. They provide a balanced and readable overview of such issues as plant siting, radiation standards and regulations, thermal effects, policies affecting energy needs of society, industrial energy resources and benefits versus risks of nuclear power. Discussions of questions raised by the audience are included at the end of each series of papers.

A particularly good, technical section on the effects of radio-nucleides is presented including a discussion of standards and of the threshold-linear response contro-

2. NUCLEAR POWER AND THE PUBLIC (cont'd.)

versy. M. King Hubbert, in his paper on "Industrial Energy Resources," provides a useful summary of his more extensive reviews (1962; 1969), and Barry Commoner, in "Nuclear Power: Benefits and Risks," raises some fundamental and interesting issues for consideration.

3. SOCIAL INSTITUTIONS AND NUCLEAR ENERGY

Author: A. M. Weinberg, Director, Oak Ridge National Laboratory.

Publisher: Science 177: 27-34, 7 July 1972.

Point of View: Optimistic. Essentially a reassurance that future science, supported by a stable, responsible society, can overcome the logistical problems introduced by nuclear energy.

Level: Non-technical.

Summary: Weinberg provides a brief description of the growth of nuclear power, of the main reactor types currently in use, and of the potential threats they pose to the environment. He then describes what he considers to be the three primary causes of concern: avoiding large reactor accidents, transport of radioactive materials and waste disposal. Weinberg stresses the statistical improbability of a major accident and describes the complex analyses which have been applied to theoretical and operations failures. Such possibilities as earthquakes or acts of violence are excused as being extremely unlikely. The discussion of the transport of radioactive materials focuses on the design of "a completely reliable shipping cask" and Weinberg notes that the Oak Ridge engineers currently have a model that looks "very promising." Some alternatives to shipping are briefly mentioned. The section on waste disposal focuses on the use of salt mine burial and the various dangers are briefly discussed.

Weinberg concludes with some thoughts on the "Faustian bargain" nuclear energy people have made with society and emphasizes the two demands which pursuit of nuclear power makes on society: First, "that we exercise in nuclear technology the very best techniques and that we use people of high expertise and purpose" and, second, the demand for longevity of human institutions, essentially as monitors for nuclear wastes. Weinberg concludes by noting that these necessary commitments are well worth the price in return for "an all but infinite source of relatively cheap and clean energy."

4. FAST BREEDER REACTORS

Authors: Glenn T. Seaborg, Chairman, U.S. Atomic Energy Commission, and Justin L. Bloom, who has served in several technical and managerial capacities on the AEC staff since 1956.

Publisher: Scientific American 223: 13-21, Nov. 1970.

Point of View: "Nuclear reactors that use fast neutrons to produce more fuel than they consume are a promising approach to producing electric power with a minimum of strain on energy resources and the environment."

Level: Non-technical; illustrated.

4. FAST BREEDER REACTORS (cont'd.)

Summary: This is essentially a description of how fast breeder reactors, particularly those cooled with liquid sodium, operate. Fission is very briefly explained and a pair of diagrams compare the thermal breeder (thorium cycle) with the fast breeder (uranium cycle). The importance of the coolant employed is noted and two breeders are described in some detail: the liquid-metal-cooled fast breeder (LMFBR) and the gas-cooled breeder that utility companies are exploring. Over half of the paper is focused on the operational details of the LMFBR-fuel and "blanket" criteria, role of the sodium coolant, function of control rods, and the two container designs under consideration (pot type and coop type) for the core-and-blanket assembly and the primary heat transfer system. The advantages of the gas-cooled fast breeder are then noted, including the fact that its design would eliminate the need for an intermediate heat exchange and that helium has several advantages over sodium. The authors conclude that "development of a gas-cooled fast breeder reactor could result in substantial additional savings beyond those that would be achieved by liquid-metal-cooled fast breeders." The extent of the USAEC effort to have breeder reactors "generating electric power on a commercial scale by 1984" is outlined and a table is provided which summarizes the characteristics and power capacities of liquid metal fast reactors built or planned. The last two pages focus briefly on three aspects of breeders: safety, cost, and environmental impact. Two "conditions to be guarded against" are mentioned: escape of radioactive waste products and loss of cooling by mechanical blockage. While the authors admit that accidents have occurred in the past, they conclude that "they will become less likely as engineering experience is gained." Several economic advantages of the LMFBR are cited, including the fact that they would conserve resources of nuclear fuel and produce power at a saving of from .5 to one mill per kilowatt hour.

5. NUCLEAR ENERGY AND THE ENVIRONMENT

Author: Alvin M. Weinberg, Director, Oak Ridge National Laboratory.

Publisher: Science and Public Affairs: Bulletin of the Atomic Scientists 26: 69-74, June 1970.

Point of View: Optimistic. A documented argument that nuclear energy can meet all the energy needs of even a population of 20 billion.

Level: Semi-technical with order of magnitude calculations of needs and resources.

Summary: Weinberg organizes this article around the energy requirements needed to provide a population of 20 billion with basic needs of air, food, water, shelter, metals, fibers etc. He then calculates the total energy required for instance to furnish water by desalting sea water, fuel by producing hydrogen electrolytically etc. and arrives at a power need requirement of 20 kwt/person.

This is followed by a useful discussion of "catalytic burning" of uranium containing rocks to fuel breeder reactors and he finds that the earth's uranium would last for millions of years.

The last part of the article deals with the environmental consequences of catalytic burning. The problem of thermal pollution can be met, he suggests, by "nuclear parks" of perhaps 40 megakilowatts each located in or near the sea. The problem of radioactive waste is considered solved by salt mine storage.

The last two or three pages of the article deal with the dangers of exposure to radiation and reactor accidents and present Weinberg's strongly felt conclusion that the promise of energy abundance which nuclear energy makes possible far outweighs the negative effects which others have emphasized.

CROSS REFERENCE

6. Science and Public Affairs: Bulletin of the Atomic Scientists 27: Nos. 7-9, September, October, November 1971. (See Ref. I-3).

7. "Controlled Fusion: Status and Outlook," D. J. Rose, Science 172: 797-808, 21 May 1967. (See Ref. VII-1).

8. "Fusion Power," Lowell Wood and John Nuckolls, Environment 14: 29-33, May 1972. (See Ref. VII-2).

V. FOSSIL FUELS

1. CLEAN POWER FROM COAL

A

Author: A. M. Squires, Chairman, Department of Chemical Engineering, City College of the City University of New York.

Publisher: Science 169: 821-828, 28 August 1970.

Point of View: Squires argues two points: "that paths of technological development exist that could lead to suppression of SO_2 from coal and at the same time to a lower cost of power; that a massive injection of money into coal engineering is the immediate ingredient necessary to open up these paths to development."

Level: Fairly technical, but not prohibitive for a general audience.

Summary: As background to his discussion dealing with SO_2 emission from coal combustion, Squires notes that the increasing legislation to limit these emissions may have some parallel to the 1863 situation in Britain when restrictions were placed on HCL emissions under the Alkalai Act. Despite industry protest, technology quickly developed, not only meeting but exceeding the new standards, and a profitable market for this once "waste" HCL was soon found.

Squires begins with a discussion of pulverized-fuel (PF) firing, the basic technique used by all large coal-power plants. Noting the "makeshift, tacked on" quality of schemes to control fly ash emissions associated with PF firing, Squires calls for "rethinking the problem with air pollution as a first rather than a last consideration." Two early emission-control schemes, Winkler's "fluidization" and Godel's "Ignifluid" are briefly described, along with some on-going U.S.-based fluidization experiments.

In "Combustion at High Pressure," a large-scale British experiment with fluidized combustion is described and illustrated. This project, which employs gas-turbine generation rather than steam generation, suggests some gains in efficiency and in cost per kilowatt and Squires suggests some modifications which might make it an even cleaner technique. Noting that a technique "as mature" as PF firing will be difficult to displace, Squires states his belief that "fluidized-bed art offers the best hope, but I should note that (others) have faith in a PF partial combustion technique."

In "Dealing with Sulfur Oxides" an alternative approach is called for which would deal with Sulfur early in the coal treating process rather than at its end. Squires notes that the National Air Pollution Control Administration (NAPCA) is currently supporting such efforts and describes some of the early results of that work, including a brief description of three available techniques for recovering Sulfur values from CaS.

A pioneering "Coalplex," directed toward recovering of Sulfur and generating clean power, is described and illustrated in "Perspective for Coal." Squires predicts that, ultimately, a coalplex might evolve for which coal power would be a relatively minor by-product, and fixed carbon would be shipped mainly for metallurgical or electrochemical use.

Squires concludes by asserting that paths of technological development that can lead to clean and cheaper power exist, but that the missing ingredient is money. Noting the uncertainties of breeder reactor technology and the shortage of low-cost uranium to carry light water reactors into the 21st century, Squires calls for an increased commitment to coal technology R & D, "Fun Money," "Spectaculars," more coal engineering establishments and more coal engineers.

2. CLEAN POWER FROM DIRTY FUELS

Author: Arthur M. Squires, Professor of Chemical Engineering and Chairman of the Department at the City College of City University of New York.

Publisher: Scientific American 227: 26-35, October 1972.

Point of View: "Considerations of both efficiency and pollution control suggest that a major effort should be mounted to generate electric power with turbines operated on 'power gas' produced from coal or oil."

Level: Non-technica. Illustrated.

Summary: This is essentially a brief "state of the art" summary on gasification of fossil fuels as a means to provide clean power. Noting the expense and difficulty of removing sulphur, the main offender, after combustion, Squires suggests concentrating research efforts on the removal of pollutants at an earlier stage in the combustion process.

Some historical precedence for this approach is documented focusing on the two-stage combustion work done by Ludwig Mond in the 1800's and the advances made in gas turbine technology in the U.S. during the two World Wars. Squires catalogues the advantages of a complete gas-turbine power installation and notes that a "feasible but imperfect" method for producing power gas from coal already exists: the "gravitating bed gasifier," or "Lurgi gasifier" in West Germany.

The operation and cost of the Lurgi system are briefly described and some of its major faults discussed. As a possible improvement on the Lurgi system, Squires proposes a fluidized-bed process that he and his colleagues at CUNY have been developing. The process is described in comparison with the Lurgi system and with credit to earlier fluidized-bed work done in Britain by F. J. Dent and in France by Albert Godel. Each of these systems is illustrated and comparative efficiency tables are provided. Another City College experiment, designed to "determine the feasibility of cleaning power gas from a proposed ash-agglomerating gasifier at high temperature" is briefly described.

Other techniques for gasifying coal, including Texaco's "slagging gasifier" and the Bureau of Mines' effort to produce substantially pure methods, are noted along with several experimental techniques for producing power gas from residual oil. Special attention is given to a British Esso effort at Abingdon as it is seen to provide encouraging results applicable to "oilplex," a scheme under study at CUNY. Squires then describes the advantages that the oilplex system promises. He concludes by hypothesizing the capabilities of future systems and notes that ". . . good technologies for providing clean power gas will be developed only if a great deal more talent is recruited for the work, and probably only with a large input of Federal money."

CROSS REFERENCES

3. "The Fossil Fuels," John Holdren in Energy, John Holdren and Philip Herrera (New York: Sierra Club), 1971, pp. 57-87. (See Ref. IX-3)

4. "Fossil Fuel Power," Section IV in Power Generation and Environmental Change, ed. David A. Berkowitz and A. M. Squires (Cambridge: MIT Press), 1971, pp. 175-343. (See Ref. III-4)

5. "When the Well Runs Dry," Robert H. Williams, Environment 14: 19-31, June 1972. (See Ref. VI-3)

6. "Energy: The Saga of the Fossil Fuels," Brian J. Skinner in Earth Resources (Englewood Cliffs: Prentice-Hall, Inc.) 1968. (See Ref. VI-2)

7. Petroleum Conservation in the United States: An Economic Analysis, Stephen L. McDonald, (Baltimore: Johns Hopkins Press) 1971. (See Ref. II-2)

VI. ENERGY RESOURCES

I. ENERGY RESOURCES

Author: M. King Hubbert, Geological Survey, U.S. Department of the Interior.

Publisher: Chapter 8 in Resources and Man, Committee on Resources and Man, National Academy of Sciences, National Research Council (San Francisco: W. H. Freeman & Co.) 1962. (259 pp.; $ 2.95)

Point of View: Hubbert is one of the most quoted and productive authors of energy resource estimates. He emphasizes the depletion of resources and the brevity of the time, measured against man's history, during which the fossil fuels, in any abundance, will be available.

Level: Thorough, technical analysis at the level of simple calculus.

Summary: Chapter 8, "Energy Resources," is the last chapter of this National Academy of Sciences report. Hubbert begins with a brief discussion of the role of energy in society and the presentation of data summarizing the production of coal, oil and natural gas from the earliest date of their exploitation. From the U.S. growth data Hubbert abstracts a common property, a constant exponential rate of growth for fifty years, more or less, followed by a period during which the rate of production drops below the linear projection of this straight line.

The bulk of the chapter is given over to a careful analysis and estimation of U.S. and world reserves of oil, natural gas, and coal. Hubbert bases his analysis on production data assuming exponential rise and decline and essentially integrating under a smoothed curve with these features. His estimates in graphic form emphasize the half-life of a resource and are thus most useful for a quick visual summary of the resource situation.

In addition to the fossil fuel estimates, which include oil shales and tar sands, Hubbert has included brief discussions of the potential of solar energy, water power, tidal power and geothermal energy. In each of these categories he has made estimates of the maximum power available.

In the next section Hubbert considers nuclear power - fission reactors of the present burner or converter type and the developing breeder type and the fusion reaction. His estimate of Uranium resources includes not only economical reserves ($10 a ton) but the low grade sources, shales and granites, which could conceivably be utilized by advanced breeder reactors.

Energy resources made available by the fusion reactions $_1D^2+_1D^2$ and $_3Li^6+_1D^2$ are also considered with estimates of reserves of $_3Li^6$ and $_1D^2$. The short supply of the former makes it a less promising source.

The next to the last section deals with the disposal of radioactive waste. Hubbert describes and criticizes present radioactive waste disposal practices and makes recommendations for their improvement.

In his final section, "Human Affairs in Time Perspective" Hubbert draws some inferences from the energy resource for mankind's future and ends with the provocative projection:

> It now appears that the period of rapid population and industrial growth that has prevailed during the last few centuries, instead of being the normal order of things and capable of continuance into the indefinite future, is actually one of the most abnormal phases of human history. It represents only a brief transitional episode between two very much longer periods, each characterized by rates of change so slow as to be regarded essentially as a period of nongrowth. It is paradoxical that although the forthcoming period of nongrowth poses no insuperable physical or biological problems, it will entail a fundamental revision of those aspects of our current economic and social thinking which stem from the assumption that the growth rates which have characterized this temporary period can be permanent.

2. ENERGY: THE SAGA OF THE FOSSIL FUELS

Author: Brian J. Skinner, Yale University.

Publisher: Chapter 7 in Earth Resources (Englewood Cliffs: Prentice-Hall Inc.) 1968. (150 pp.; $ 2.75).

Point of View: Optimistic. "Though cause for concern, the situation is probably not cause for alarm. In the first place the growth rate is unlikely to continue; in the second place, assuming that the efficient oil industry will find, develop, and extract . . . man has a transition period ahead . . . "

Level: This is one of a series of elementary earth science books in the Foundations of Earth Science Series and is written at the level of a freshman non-science student.

Summary: This short chapter is an excellent companion article to Hubbert's chapter in Resources and Man (see Ref. VI-1). It contains much useful detail on the formation, composition and geographic distribution of the fossil fuels but does not provide the careful estimation of resource reserves that Hubbert does. It includes not only the big three fuels but tar sands and oil shale and has a brief discussion of nuclear energy with data on Uranium reserves of various grades of purity.

3. WHEN THE WELL RUNS DRY

Author: Robert H. Williams, Assistant Professor, Harrison M. Randall Laboratory, University of Michigan, Ann Arbor.

Publisher: Environment 14: 19-31, June 1972.

Point of View: "As natural gas resources become depleted, methane from organic wastes is likely to become more and more attractive."

Level: Non-technical; illustrated. Bibliography.

Summary: The purpose of this article is to outline some of the difficulties which will effect natural gas policy as demand for clean fuels continues to grow. Williams argues that, if current estimates are in the right ball park, "natural gas is not likely to remain a significant energy resource much beyond the turn of the century."

In "The Future Demand for Natural Gas" Williams notes the discrepancies in the various resource estimates and examines the highest (Institute of Gas Technology) and lowest (Dept. of Interior) projections in terms of their assumptions. The question of whether or not natural gas can continue as a major energy source for the long-term future is addressed in the next section, "The Supply of Natural Gas." Gas supplies are examined just in terms of the resource base and Williams questions the accuracy of making such estimates on the basis of the demonstrated correlation between natural gas and petroleum finds. A comparison of the heat content of the resource base for each of the three major fossil-fuel energy resources is provided.

In "Ultimately Recoverable Resources" two "noteworthy and different" estimates, one by T. A. Hendricks and one by M. K. Hubbert, are compared on the basis of methodology as " . . . they are straight forward and indicative of the primitive state of the art in resource estimation." Again, heat values are compared for the different fuels and the limited supply of natural gas resources is emphasized.

Those deposits of natural gas whose location is already known are examined in "Proved Reserves." Williams notes the difficulty of predicting supply-demand patterns over the next decade, but suggests that in the longer term, substitutes for domestic natural gas will be essential.

3. WHEN THE WELL RUNS DRY (cont'd.)

Such substitutes are then described including potential imports from Canada and Mexico and increased liquified natural gas imports from South America and Africa.

Several alternatives to heavy reliance on imports are then discussed. In "Nuclear Stimulation of Gas Reservoirs," two Plowshare experiments, Project Gasbuggy and Project Rulison are briefly reported and the environmental difficulties associated with them carefully dilineated. Finally, "Synthetic Gas" and "Gas From Organic Waste" briefly treat the possibilities of coal gasification and methane production.

CROSS REFERENCES

4. "The Energy Resources of the Earth," M. King Hubbert, Scientific American 224: 60-70. (See Ref. I-2).

5. "Industrial Energy Resources," M. King Hubbert in Nuclear Power and the Public, ed. Harry Foreman (Minneapolis: University of Minnesota Press) 1970, pp. 179-207. (See Ref. III-4).

VII. FUTURE SOURCES OF ENERGY

1. CONTROLLED FUSION: STATUS AND OUTLOOK

Author: D. J. Rose, Director of Long Range Planning, Oak Ridge National Laboratory.

Publisher: Science 172: 797-808, 21 May 1967.

Point of View: Optimistic. "Scientifically speaking, controlled fusion is probably attainable . . . The real questions of fission breeders versus fusion breeders involve feasibility, relative cost, time scales and environmental factors . . . My own guess is that fusion power will be available in appreciable quantity by 2000 . . . "

Level: For the most part, this is a paper on the technological problems of attaining controlled fusion reaction, written on a fairly technical level for an audience which has some familiarity with modern physics. Illustrated.

Summary: Rose is concerned here with four major topics: how things are now, what is still needed to demonstrate scientific feasibility, what more is needed to make a practical fusion reactor, and how fusion does or does not fit out supposed future requirements.

Noting that "the worst problem is presented by the nature of the reaction itself," Rose begins with a brief description of the reaction (with illustrations) and a discussion of the main schemes (including the Toroidal System and the Tokamak) now being developed to contain the fuel plasma. The Tokamak device is described as the most hopeful and operating details of the largest existing one are provided. Rose concludes that "divinations from plasma physics may permit or deny the possibility of useful power from controlled fusion, but they cannot guarantee it." He then discusses a number of applied problems that are "substantially independent of the particular geometric model," including those of plasma engineering, regenerating tritium, heat deposition, providing large quantities of high magnetic field and structure to withstand stress, radiation damage and size and cost. Three "Model-Dependent Problems" (fuel injection into closed toroidal systems; fast-pulsed systems) are then briefly discussed and a "Fearless Forecast" provided which details the bases for Rose's prediction that fusion power will be available in appreciable quantity by 2000.

The final two sections, "Hazards" and "Other Environmental and Technology Assessment Questions," include a discussion comparing the potential nuclear hazards of fission versus fusion (tritium) reactors and an argument based on the growing non-electric energy demands that, "if fossil fuels are to be substantially traded for nuclear ones, nuclear power plants must be built in or very close to population centers." Total social costs and benefits are briefly discussed and nuclear fission is described as capable of being made "substantially more attractive than coal or oil, for most purposes."

2. FUSION POWER

Authors: Lowell Wood, Physicist at the Director's Office of the University of California Lawrence Livermore Laboratory, and John Nuckolls, Physicist and Associate Division Leader, Nuclear Explosive Design, University of California Lawrence Livermore Laboratory.

Publisher: Environment 14: 29-33, May 1972.

Point of View: "The oldest CTR approaches are not necessarily the ones which will most quickly lead to "break-even" level of fusion energy production, or to the first CTR power plants. New approaches . . . will apparently constitute justifiably strong competition with more venerable CTR schemes . . . "

Level: Non-technical; illustrated.

Summary: Four new approaches to CTR are presented here as possible alternatives to the "conventional" technologies being explored under the AEC-CTR program: microwave confinement, magnetically confined laser-heated plasmas, implosions of relativistic beam-preheated fusion fuel and laser fusion. Each relies on relatively new technologies, has origins and financial support outside of the AEC, and has thermonuclear plasmas which are not magnetically confined. A description of each technique is provided along with a brief evaluation as to its prospects for success.

3. POWER FROM THE SUN: ITS FUTURE

Author: Peter E. Glaser, Head of the Engineering Sciences Section at Arthur D. Little, Inc., Cambridge, Mass.

Publisher: Science 162: 857-861, 22 Nov. 1968.

Point of View: "The conversion of solar energy to usable power is the only alternative to nuclear power for the distant future . . . In future years solar energy will become increasingly essential for the continued evolution of power-generating plants."

Level: Non-technical; illustrated.

Summary: This is a paper not so much on solar energy itself, but on a "Satellite Conversion System" which would make solar energy viable in the future. In the introductory paragraphs Glaser briefly reviews the status of "Energy Resources," noting that, by the year 2000, "30 percent of the total power requirement will have to be met by energy sources other than those available today." Glaser points out that, given the uncertainty of fusion-generated power, the thermal pollution associated with nuclear plants and the time-lag between the conception and operation of new power plants, "new energy sources will not be providing power in significant quantities within the next half century." Glaser proposes the conversion of solar energy to usable power as the major alternative for the future.

Three major categories of possible uses of solar energy proposed and briefly illustrated are: research uses not necessarily directed toward the production of power; various applications, including power generation for developing countries; use for power generation in technologically advanced countries.

Most of the paper is then directed toward discussion of a "Satellite Conversion System" which is proposed as an answer to the present economic difficulties of generating power from solar energy on earth. Four major technological problems are isolated and discussed: orbit characteristics, conversion devices (particularly as they relate to efficiency), transmitters and earth receiving stations. Glaser concludes that "projects such as the development of solar power may prove to be a logical outgrowth of achievements in space."

4. POWER FROM THE EARTH

Authors: David Fenner, Graduate Student in Physics, Washington University and Joseph Klarmann, Associate Professor of Physics, Washington University and member of the Scientific Division of the Committee for Environmental Information.

Publisher: Environment 13: 19-34, December 1971.

Point of View: This is a survey article which deals with geothermal energy as one alternative to nuclear and fossil-fueled power plants. While the authors note that "numerous questions about the suitability of geothermal power for large-scale production remain largely unanswered," they conclude that "despite a few important areas of uncertainty, the future for geothermal power looks very bright."

Level: Non-technical. A number of useful tables, illustrations and diagrams are provided.

Summery: This is a four-part survey paper addressed to the question of the viability of geothermal energy as a means of producing electric power. Current "state of the art" information is provided on mecha-

4. POWER FROM THE EARTH (cont'd.)

nisms of production, and the areas of cost analysis and world resources are examined briefly with the understanding that "considerable confusion and disagreement" prevent a thorough treatment of either topic.

In section one, "The Origin and Production of Geothermal Power," the geologic sources of heat are described, two methods for geothermal exploration (temperature-sensing and geologic-structure investigations) are briefly mentioned, and geothermal wells are described and contrasted with petroleum wells. The section concludes with a discussion contrasting non-condensing and condensing types of geothermal power generating plants.

"Actual and Probable Costs" are described in the second section with the understanding that "the economics of geothermal-electric power production are still rather uncertain." The authors note, however, that "estimates made so far indicate that geothermal power is strongly competitive in cost with conventional sources of electricity." Costs of exploration, well-drilling and power plants are provided in terms of actual costs of on-going geothermal projects. Additional costs, such as those of pipelines, operation and maintenance and the cost of land are treated very briefly and two potential economic assets, chemical recovery and distillation of fresh water, are mentioned. "Environmental costs" are treated under a separate heading and the topic is introduced with the warning that "although geothermal energy has the appearance of being a relatively pollution-free and environmentally safe source of electrical power, things are just not that simple." Problems of the existence of potentially harmful trace impurities, the effects of drilling on fresh water tables (as in Imperial Valley, California), and several problems associated with injection plans are noted. A table is provided which gives a cost comparison of geothermal power (projected) with other conventional sources of electrical energy.

"World Geothermal Resources" are dealt with in the third section and known natural resources and suspected natural resources are located. "Nuclear Stimulation" is briefly described and the authors conclude that " . . . it is highly inadvisable to pursue nuclear stimulation at this time." The question of well and field life time is discussed in a few paragraphs and it is suggested that additional research and experience are needed before reliable estimates can be given.

In the concluding section, "Recommendations for the Future of Geothermal Power," the authors point out the importance of conducting extensive research into possible problem areas of geothermal power "before full-scale investment in production systems occurs" and suggest a number of important questions that need to be answered. The authors question the advisability of having geothermal power in the U.S. "developed and hence owned by the oil industry" and suggest that geothermal resources be placed largely under federal control and investment and that "those who exploit geothermal resources be required to submit an environmental impact statement prior to extensive development."

5. GEOTHERMAL POWER

Author: Joseph Barnea, Director of the Resources and Transport Division of the United Nations.

Publisher: Scientific American 226: 70-77, January 1972.

Level: Popular; illustrated.

Point of View: Some of the pressure on energy resources could be alleviated through increased research on exploration and development of geothermal power which promises to be a clean, relatively cheap and widespread, multipurpose energy source.

Summary: The focus here is on new concepts for

5. GEOTHERMAL POWER (cont'd.)

exploring geothermal resources and in developing interdisciplinary and multipurpose approaches to both exploration and development. Barnea begins with a brief recounting of the medicinal and recreational role that "hot springs" have had in history and explores several reasons for the slow development of geothermal power as an energy source. One of the main problems cited is that exploration has been limited to those deposits which are marked by some surface sign, creating the impression that geothermal resources are highly localized and minor. In contrast to this Barnea describes three classes of sources - dry steam fields, wet steam fields and low temperature fields - and illustrates each as to physical characteristics, geographical location and existing exploratory operations. It is clear from the review that, in fact, geothermal resources are widespread and that "as new information becomes available the magnitude of geothermal energy resources is beginning to be appreciated." Barnea emphasizes the need to develop geothermal power as a multipurpose resource and gives numerous examples of existing wells that are being put to varied uses. The special costs of geothermal power are briefly discussed and it is shown to be a relatively inexpensive power source, particularly when used for more than one purpose. Environmental costs are then considered and Barnea notes that, while geothermal energy can be used "at little or no cost to the environment," there are two potential hazards, chemical discharge and land subsidence, that need to be and can be controlled. Barnea concludes by emphasizing the need for research in the development of techniques of exploration to search for geothermal reservoirs, hidden as well as visible.

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6. "Fusion Power: The Uncertain Certainty," R. F. Post in "The Energy Crisis: Part II," Science and Public Affairs: Bulletin of the Atomic Scientists 27: 42-48, October 1971. (See Ref. I-3).

7. "Solar Power," Norman C. Ford and Joseph W. Kane in "The Energy Crisis: Part II," Science and Public Affairs: Bulletin of the Atomic Scientists 27: 27-31, October 1971. (See Ref. I-3).

8. "Is It Time For a New Look at Solar Energy?" Aden Baker Meinel and Marjorie Pettit Meinel in "The Energy Crisis: Part II," Science and Public Affairs: Bulletin of the Atomic Scientists 27: 32-37, October 1971. (See Ref. I-3).

9. "Geothermal Energy: The Neglected Energy Option," Robert W. Rex in "The Energy Crisis: Part I," Science and Public Affairs: Bulletin of the Atomic Scientists 27: 52-56, October 1971. (See Ref. I-3).

VIII. DATA

1. THE 1970 NATIONAL POWER SURVEY

Author: Prepared by the Federal Power Commission.

Publisher: U.S. Government Printing Office, Washington, D.C., December 1971. (~1500 pp.; $ 19.50; four volumes.)

Point of View: "The Commission report is intended to serve as a general long-range guide rather than a directive or firm plan. It illustrates possible patterns of efficient development based upon assumptions outlined in the report . . . "

Summary: The National Power Survey "projects electric load growth over the next twenty years, and discusses changing power technology, growing concerns for all developments, including use of resources and various impacts on air, water and land, increasing problems in meeting schedules for needed new power facilities, power plant fuel supply problems, and the probable effect of these on the cost of power. . .

The survey is reported in four parts. Part I contains the report of the Commission and the report of the Task Force on Environment. Parts II and III contain the reports of the six regional advisory committees. Part IV contains the reports of the technical advisory committees on generation, transmission, distribution and load forecasting methodology."

2. PATTERNS OF ENERGY CONSUMPTION IN THE UNITED STATES

Author: Prepared by Standford Research Institute for the Office of Science and Technology.

Publisher: U.S. Government Printing Office, Washington, D.C., January 1972. (220 pp.; $ 2.25)

Point of View: "The report is strictly a factual document; its purpose is to provide the most detailed information practicable on how the nation uses its energy."

Summary: This study was commissioned to dilineate four aspects of U.S. energy consumption: the significant purposes (end uses) fuels have been used for in the U.S.; the portion of the nation's energy requirements for the various end uses which have been met by each fuel; the rate of growth of consumption in the major end uses of each fuel and the technical efficiency which can be expected when each fuel is used for those end uses for which it is suitable.

Although the emphasis of the study is on the residential, commercial and industrial sectors, data is presented on the use of electric power and on the transportation sector in order to arrive at a total energy balance. As explained in the introduction to the report, "the study deals only with energy consumption in the recent past; there are no projections of energy demand, nor are there observations as to the significance of the results to the future or to policy considerations."

The data presented here is from three main sources: the annual U.S. Bureau of Mines consumption data, personnel of the major energy consuming industries and trade associations, government agencies, etc. Much of the end use information has been "estimated or inferred in the absence of adequate recorded data."

A brief summary of the study findings is presented at the beginning of the report and separate chapters are designated for The Residential Sector, The Commercial Sector, The Industrial Sector, The Transportation Sector, and Efficiency of Fuel Utilization. Within each "sector" chapter, data is presented on total consumption of energy and on each separate end use, i.e. space heating, water heating, cooking, petroleum refining, etc. Numerous illustrations and tables are presented throughout the report.

3. ENERGY IN THE AMERICAN ECONOMY, 1850 - 1975

Authors: Sam H. Schurr (director) and Bruce C. Netschert, Vera F. Eliasberg and Hans H. Landsberg (research associates, Resources for the Future, Inc.).

Publisher: Published for Resources for the Future, Inc. by the Johns Hopkins Press, Baltimore, 1960. (774 pp.; $ 15.00)

Summary: There are almost 200 tables and figures in this digest, providing not only historical data on consumption and production of energy but also data on almost every facet of recent and projected consumption and use. In the introduction and summary chapters Schurr discusses energy consumption and availability in 1975, energy consumption and national growth (past and prospective) and the possible impact of atomic energy.

The remainder of the study is divided into three parts. Part I, "A Century of Energy Use: 1850 -1955," deals with the changing level and pattern of energy uses, the record of the major energy sources (fuel wood, coal, oil, natural gas) and "Some Aspects of Energy Consumption in Relation to U.S. Economic Growth" (rate of increase, per capita consumption, changes in the energy economy, etc.). A brief summary section discusses the findings in terms of possible causes of the growth in consumption.

Part II, "The Future of Energy Consumption," contains two chapters. The first, "Concepts, Scope and Method in Estimating Future Energy Consumption" discusses overall economic assumptions and derivation of the estimates (industrial, commercial, household, etc.). The second chapter, "Summary of the Energy Consumption Estimates" treats the level and composition of energy consumption and consumption patterns according to sectors (coal, oil, etc.) and energy sources (industry, commercial, etc.).

Finally, Part III, "The Future of Energy Supply," examines the conceptual basis of energy supply estimation and then focuses one chapter each on coal, crude oil, natural gas and natural gas liquids, and hydropower. Within each chapter, the reserve-resource position is delineated along with estimates of future capacity and production, discussion of the technology involved and a look at other sources of supply.

4. ENERGY IN THE UNITED STATES, 1960 - 1985

Author: Michael C. Cook.

Publisher: Sartorius & Company, New York, 1967. Out of print; available in libraries.

Point of View: Prepared by Sartorius & Co. members, New York Stock Exchange, as background for their investors.

Summary: "This report contains the results of a seven-month study of fuel and electricity consumption trends in the United States, including projections of consumption patterns through 1985. Energy use is analyzed on a geographic basis, with the United States broken down into ten regions. Within each region, energy requirements are studied for each major use, i.e.: Residential and Commercial, Industrial, Transportation and Utilities. The social, economic and technical factors which will affect competition among the various fuel products and electricity are analyzed."

Chapters I, "conclusions," and II, "Introduction and Summary," briefly review the findings of the study. Chapter III describes the assumptions, definitions and methods of analysis used in the study. Technical, economic and social factors which influence competition for U.S. energy markets are discussed in Chapter IV, "Technoeconomic Factors." The ten regional chapters follow and the study concludes with a brief discussion of nuclear power, i.e. Technology of Nuclear Power Plants, Economics and Competitive Market Positions of Nuclear Power Plants, Nuclear Power Plant Economies, the Competitive Position of Nuclear Power, Uranium Inventory, Breeder Reactors, etc. Useful tables and illustrations are presented for each section.

5. THE NUCLEAR INDUSTRY 1970

Author: Prepared by the Division of Industrial Participation, U.S. Atomic Energy Commission.

Publisher: U.S. Government Printing Office, Washington, D.C., November 18, 1970.

Point of View: "This booklet is published annually to present AEC's assessment of the state of the nuclear industry and make available facts believed to be of interest and in accordance with the President's program to improve service to the public."

Summary: Information is presented here under eight major categories and in five special topic chapters. A brief summary section, dealing with shipments of products, employment, investment, exports and nuclear-electric power, introduce the volume. This is followed by "Nuclear Industry Highlights," an eight-page summary of the year's highlights in civilian nuclear power, plowshare, interstate agreements, etc. A separate section is also provided on "Private Ownership - Toll Enriching," which presents a q[illegible] profile of progress under the AEC private ownersh[illegible].

Category I, "Raw Fuel Materials," provides data on Uranium and Thorium. "Materials Processing and Fabrication," Category II, deals with Uranium enriching, Plutonium processing, heavy water, etc. Data on "Nuclear Components and Equipment" and "Reactors" is detailed in Categories III and IV respectively. Remaining categories deal with Radioisotope and Radiation Applications, Materials Reprocessing, Plowshare, and Services.

Special chapters on "Proposed Legislation," "Licensing and Regulation," and "Assistance for Industry" outline the year's developments in nuclear policy.

6. THE NUCLEAR INDUSTRY 1971

Author: Prepared by the Division of Industrial Participation, U.S. Atomic Energy Commission.

Publisher: U.S. Government Printing Office, Washington, D.C., 1971, WASH 1174-71. (199 pp.; $ 1.75)

Point of View: "Over the past ten years these annual reports on the industry have been prepared ... to make information available to the public on the growth of the private nuclear industry and to summarize the policies of the AEC which have had an impact on the industry."

Summary: Previous annual reports in this series have been intended partly as "introductory reading for persons desiring to become better acquainted with the nature and extent of private enterprise in the nuclear field." The 1971 edition, however, has been reduced in size and does not contain much of the background material available in the 1970 edition, including "Nuclear Industry Highlights." It does, however, contain up-to-date data in several categories: Raw Fuel Materials, Materials Processing and Fabrication, Nuclear Components and Equipment, Reactors, Radioisotopes and Radiation Application, Materials Reprocessing, Plowshare, Peaceful Uses of Nuclear Explosives, and Services. Some information is also provided separately for licensing and testing and "assitance for Industry."

7. ENERGY IN THE WORLD ECONOMY: A STATISTICAL REVIEW OF TRENDS IN OUTPUT, TRADE, AND CONSUMPTION SINCE 1925

Author: Joel Darmstadter, senior research associate, Resources for the Future (RFF), with Perry D. Teitelbaum and Jaroslav G. Polach.

Publisher: Published for Resources for the Future, Inc., by The Johns Hopkins Press, Baltimore, 1971. (876 pp.; $ 22.50).

Summary: "This book deals with quantitative aspects of long-term trends in energy consumption, production, and foreign trade; and, more particularly, with the transformation, during this century, of the world's fuel base away from coal and toward oil and natural gas.

In reviewing these developments, the book sets out to accomplish three main tasks. The first, upon which the others depend, is to assemble statistical series depicting movements in consumption, production, and international trade of energy commodities since 1925 by countries, regions and the world as a whole. Secondly, these voluminous statistical materials are winnowed in order to bring into sharp focus the main features of those movements. The third task is to relate these main features to other economic variables and, in so doing, to provide an essential springboard for anyone wishing to evaluate prospects for the future.

Part one describes and interprets the significant statistical findings. Part two presents a series of statistical profiles, each dealing with some unique facet of the overall picture. These profiles are derived from the detailed statistics in Part three. Part four deals with questions of methodology and definition connected with the detailed statistical series, and also provides country-by-country source notes. Part five presents selected supplementary materials: on energy and gross national product, matrix tables of international energy flows, and a brief bibliography."

8. THE 1969 STATISTICAL YEARBOOK

Author: Statistical Office, United Nations.

Publisher: Statistical Office of the United Nations, Department of Economic and Social Affairs, New York, 1970. (770 pp.; $ 19.00)

Summary: Data on the world's energy profile make up only a small fraction of the statistical information in this volume. Other areas covered include population, manpower, agriculture, forestry, fishing, industrial production, mining and quarrying, manufacturing, construction, internal and external trade, transportation, communication, consumption (food, wool, etc.), balance of payments, wages and prices, finance, international capital flow, health, housing, education and mass communication.

There are five tables in the Energy section. The first, "Output and Employment in Electricity and Gas," provides a description of the structure of the gas and electricity industry in the various countries. Other tables include one on the world's production and consumption of energy, one on installed electric capacity for each country, a summary of electric energy production throughout the world and a table on the world's manufactured gas production. Data on natural resources (coal, crude oil, etc.) is presented in the Mining and Quarrying section.

IX. STUDENT READING

1. THE NEXT HUNDRED YEARS

Authors: Harrison Brown, geochemist; James Bonner, biochemist; John Weir, psychologist; all of the California Institute of Technology.

Publisher: The Viking Press, New York, 1957. (193 pp.; $ 1.45).

Point of View: "When we take the very long view of man's world in the next century we see that the main problems are less those of technology than they are those of men's getting along with other men, communicating with other men, and organizing themselves in such a way that their genius and imagination can be vigorously applied to the problems that confront them."

Level: Popular.

Summary: Considered a classic in environmental literature, this exploration into the future of the earth's natural resources in relation to man and his technology deals with the limits which must ultimately bound the development of an industrial society and the problems which must be faced as those limits are approached. Problems such as: How long can we sustain the current rate of material progress and growth? Will we level off? Can we foresee the major problems that will confront us? What kind of society could our science and technology help us to create in a world at peace?

After a brief discussion of the difficulties and limitations inherent in predicting the future, the discussion focuses on a comparison of the way of life in an industrial society (the U.S.) with that in a non-industrialized one (India). This leads into the question of per capita consumption of raw materials and, eventually, into a discussion of the factors which will determine the future supply and demand for raw materials. Succeeding chapters deal with the accompanying problems of producing sufficient technical manpower in an industrial society, rate of industrialization, world population, world food production and patterns of agricultural change.

Several chapters are given over to the specific problems of energy demand and consumption in an industrialized country. The necessity of processing lower and lower grade ores, of finding "substitute materials" for diminishing resources and of providing new technologies to meet these changes are dealt with in terms of their over-all cost. Patterns of energy production and consumption are provided along with estimates of the world reserves of fossil fuels and some discussion of the uneveness of their geographical distribution. Several "new"sources of energy, including solar batteries, nuclear fission and fusion are briefly discussed.
Concluding chapters focus more closely on the problem of providing technical manpower and on the increasing necessity of concentrating man's efforts, not on economic competition between nations, but on "achieving peace and an abundant life for all the world's people."

2. THE LIMITS TO GROWTH

Authors: Dennis L. and Donella H. Meadows, Jørgen Randers and William W. Behrens III.

Publisher: A Potomac Associates Book (New York: Universe Books)1972. (204 pp.; $ 2.75)

Point of View: "The earth's interlocking resources - the global system of nature in which we all live - probably cannot support present rates of economic and population growth much beyond 2100, if that long, even with advanced technology."

Level: Non-technical.

Summary: The Limits to Growth reports the conclusions of an eighteen month project sponsored by The Club of Rome and undertaken at MIT by an international team of scientists. The task of the project was to develop a computerized model of global environmental and social systems in order to determine the implications of five factors on the future: world population growth, industrialization, pollution, food production and resource depletion.

2. THE LIMITS TO GROWTH (Cont'd.)

The report is divided into five parts, each dealing with a different aspect of the growth problem. Chapter I, "The Nature of Exponential Growth," focuses on population and economic growth and provides an elementary introduction to the mathematics of exponential growth (doubling times, feedback loops, etc.).

Chapter II, "The Limits to Exponential Growth," deals with the physical ingredients necessary to sustain world economic and population growth: food consumption, agricultural production, nonrenewable resource use and pollution control. "Growth in the World System," Chapter III, examines the complex way in which growth variables interact and the implications this complexity has for extrapolation predictions. The purpose, structure and quantitative assumptions of The Club of Rome model are then briefly described.

In Chapter IV, "Technology and the Limit to Growth," the model is used to test the possible consequences of the new technologies that promise to raise the limits to growth. Several implications of new approaches to energy needs, pollution control, increased food yield and birth control are factored into the model and it is shown that, change or no change, the same conclusion holds: "The basic behavior mode of the world system is exponential growth of population and capital, followed by collapse." Technological "side effects" and problems for which there are no technological solutions are then briefly examined and a set of questions suggested which need to be answered before the adoption of any new technology.

The final chapter, "The State of Global Equilibrium," reviews deliberate restraints on growth, the potential for growth (except for population and capital) in the equilibrium state and problems involved in the transition from growth to gobal equilibrium. A commentary at the end of the report provides some reflections by the Executive Committee of The Club of Rome.

3. ENERGY

Authors: John Holdren, physicist at the University of California's Lawrence Livermore Laboratory and Philip Herrera, environment editor of Time magazine.

Publisher: A Sierra Club Battlebook (New York: Sierra Club) 1971. (252 pp.; $ 2.75)

Point of View: This is one of a series of Sierra Club Battlebooks aimed at servicing "the growing student environmental movement on the nation's campuses."

Level: Popular.

Summary: This is really two books in one: a textbook on energy and a handbook for environmental activists. In part one, "Energy: Resources and Consumption," Holdren reviews the fundamentals of energy: Trends in energy use, forecasts of future consumption, the crisis, the fossil fuels, hydroelectric energy, nuclear fission, thermal pollution and climate, future energy sources and various aspects of demand. Aimed at a popular audience, the text provides a summary description of the energy question without going deeply into any of the associated physics or mathematics.

Part two, "Power: Conflicts and Resolutions," is the work of Philip Herrera. Some of the major recent controversies over the siting and operation of power plants are dealt with in the eight chapters in this section: The Four Corners, Commonwealth Edison, Storm King and Calvert Cliffs, Bodega Head, Monticello, Cayuga Lake, Biscayne Bay, Lake Michigan and Berkshire-Litchfield. In each of the chapters Herrera provides an opening section in which he sets the background of a specific environmental crisis situation, followed by a brief summary of the role private citizens have played in the controversy. It is in this section that the Sierra Club's commitment to conservation comes through most strongly.

4. ENERGY

Author: Mitchell Wilson, physicist and author of non-fiction and novels, and the Editors of Life.

Publisher: Life Science Library, Time Inc., New York, N.Y., 1963. (200 pp.; $ 5.70).

Level: Popular. Illustrated.

Point of View: This is one in a series of volumes which comprises the Life Science Library, each written with the idea that science can be made interesting to a general audience through the use of good illustrations and simple literate text.

Summary: This is very much a "Life Magazine" approach to energy with a fairly elementary written text alternating with picture essays. The role of energy in the universe is briefly explained and the basic types of energy - including heat, light and electricity are examined. All in all, this is a very readable volume, providing interesting historical detail and imaginative use of illustration and example.

5. THE CLOSING CIRCLE

Author: Barry Commoner, Director, Center for the Biology of Natural Systems, Washington University, St. Louis.

Publisher: Bantam Books Inc., New York, N.Y. (299 pp.; $ 1.95).

Point of View: Man has seriously overloaded several of the most important ecological cycles and has but a few decades to correct the damage.

Level: Popular; Commoner develops the necessary background information in the early chapters, then diagnoses and prescribes.

Summary: This is not a book on the energy crisis as such but rather a broad treatment of the entire environmental crisis. It does, however, provide a background against which to view the energy crisis and in several sections deals directly with aspects of that crisis.

The first six chapters, roughly the first third of the book, present examples of the overloading of important ecological cycles in air, water, and soil. The middle section of four chapters analyses these breakdowns and searches for cause. It is in this section that Commoner considers the two most popular environmental villains, population and affluence, and discards them in favor of misdirected technology. His major thesis and the most provocative aspect of the book is that technology is replacing natural methods and products (which are economical in their demands for energy and their impacts on ecological systems)with energy intensive synthetic products and methods. This replacement underlies, he argues, the energy crisis and the environmental crisis which accompanies it. He provides convincing examples of "agribusiness," replacement of paper by plastics, soap by detergents, steel by aluminium, etc.

The final third of the book examines the social and economic roots of some of these problems and suggests the nature of some of the changes which may have to occur if humankind is to "close the circle" and "restore to nature the wealth that we borrow from it."

This book is an important supplement to those more narrowly concerned with the "energy crisis" as it reminds us that that topic, multifaceted as it is, must itself be understood, and solutions tested, against the larger web of life's ecology.

6. THE CONCEPT OF ENERGY SIMPLY EXPLAINED

Author: Morton Mott-Smith, British physicist.

Publisher: Dover Publications, Inc., New York, 1964. (215 pp.; $ 2.00)

Point of View: This is an historical account of the understanding and harnessing of heat energy and predates the present concern of the "energy crisis."

Level: Elementary college science level; some technical exposition in the form of graphs and formulae.

Summary: This short Dover reprint provides an entertaining and useful discussion of heat energy, heat engines, and the First and Second Laws of Thermodynamics. The presentation is strongly historical and thus provides a much different viewpoint to such topics as theory of heat, of energy conservation, entropy, etc. than would be found in any standard treatment of energy.

The organization is somewhat different from the usual form of presentation. The first six chapters recount the development of the steam engine and the ideas which lead to understanding heat engines in general. The next eight chapters trace the development of the law of conservation of energy. The controversy between the Mayer and Joule point of view is recounted in historical detail; the confrontation of the Caloric and heat-as-motion theories and the experiments which finally established the latter are described. Joule's experiments on the mechanical equivalent of heat, discussions of perpetual motion and an historical examination of the development of the concept of energy make this a very useful section.

Chapters sixteen and seventeen then introduce and discuss the Second Law of Thermodynamics and its implications for the energy picture, and the concept of entropy which is presented both in its formal guise as Q/T and as a measurement of the movement from order to disorder. This latter discussion is qualitative and helpful to the reader without a physics or mathematics background.

The last three chapters deal in more detail with the operation of heat engines - hot air and steam - internal combustion engines, and refrigerators and serve as useful explanations of such devices.

The book will be helpful in a course on energy either as a source book for the instructor or as a source of supplementary reading assignments for students on any of the broad category of topics it covers.

7. NIGHT COMES TO THE CUMBERLANDS

Author: Harry M. Caudill, lawyer and Kentucky ex-legislator.

Publisher: Little, Brown and Co., Boston 1962. (394 pp.; $ 2.45).

Point of View: Conservationist. "The price we pay for wanton spoilation is sure and certain. In the highest sense, conservation of the land is the conservation of human life. The two have always been, and will always be, inseparable."

Level: Popular. Several photographs included.

Summary: Subtitled "a biography of a depressed area," this is the story of what the discovery of coal and the growth of the coal industry have done to the land and people of the Cumberland Plateau. Beginning with the settlement of the area in the middle 1700's, Caudill traces the history of the Plateau through the division and family feuds of the Civil War, the coming of the railroad and growth of the lumber and coal industries, the "Big Boom" and the depression that followed, the emergence of the unions, the "Rise of the Welfare State" and the scene today, complete with a thorough discussion of the complexities of the strip-mining controversy. This is an emotional book, with its emphasis on the destruction of the spirit of the "highlander," the descendents of the settlers who first opened the way into the mountains of Kentucky. Caudill concludes by noting: "The essential element of the plateau's economic malaise lies in the fact that for a hundred and thirty years

7. NIGHT COMES TO THE CUMBERLANDS (cont'd.)

it has exported its resources, all of which - timber, coal and even crops - have had to be wrested violently from the earth. The nation has siphoned off hundreds of millions of dollars worth of resources while returning little of lasting value. For all practical purposes, the plateau has long constituted a colonial appendage of the industrial East and Middle West, rather than an integral part of the nation generally." Caudill's approach, to set this "price" in people and land against the cost of our increasing appetite for coal, makes for a most impressive and thoughtful account.

8. THE CARELESS ATOM

Author: Sheldon Novick, editor Environment magazine.

Publisher: Houghton-Mifflin & Co., Boston, 1969. (225 pp.; $ 5.95)

Point of View: Anti-nuclear reactor. The dust jacket quotes Edward Teller: "In principle nuclear reactors are dangerous . . . In my mind, nuclear reactors do not belong on the surface of the earth."

Level: Popular.

Summary: With The Careless Atom Sheldon Novick has tried to do for nuclear reactors what Rachel Carson's Silent Spring did for pesticides. While this is not a text book in any sense of the word, it does raise a number of questions that could form the basis for an excellent course.

There are nine chapters in all: "Accidents Happen," which describes some of the more spectacular reactor accidents in interesting detail; "Turning Swords into Plowshares," which provides a quick trip through the development of nuclear energy to the present; "Earthquakes and Accidents," which considers the West Coast reactors, particularly the one planned for California's Bodega Bay; "The Problem of Insurance," which covers just that; " Radiation Damage," which considers the complex biological and physical interactions of radioactive materials; "A New Pollution Problem," which looks at the leaks; "The Coming Thing," which suggests we not go so fast; "Why Reactors," which attempts to set fissile fuel in the context of total fuel resources and energy needs; and a final chapter, "Information and Action," which makes the pitch for the 'scientific information movement.'

While there is some weakness in the treatment of basic science content, the discussion of the complex problems that have beset the nation's efforts to put the nucleus to work are excellent. Descriptions from records of hearings, technical articles, public speeches, etc. have been carefully compiled and are well documented in numerous footnotes. Novick has woven a fascinating picture of the interplay of technological experimentation and political and economic pressure.

9. DIRECT USE OF THE SUN'S ENERGY

Author: Farrington Daniels, Solar Engineering Laboratory, Engineering Experiment Station, University of Wisconsin.

Publisher: Yale University Press, New Haven, 1964. (362 pp.; $ 10.00)

Point of View: "The direct use of sunlight to supply the basic human needs for energy is of primary importance to man's continued survival on earth, for the stored fuels, fossilized or organic, are being consumed at an incredible rate."

Level: Non-technical. A number of tables and illustrations are provided.

Summary: This is really a dual purpose book, aimed both at encouraging increased solar research, particularly in the non-industrialized countries, and in interesting the general reader in some of the fascinating possibilities solar energy holds for the future. A brief introductory section emphasizes the importance of solar energy as a supplement to the rapidly decreasing fossil fuels and details its numerous advantages. Early experiments in solar energy are quickly reviewed and a brief summary of solar symposia in the 1950's and 1960's provided. Some of the basic aspects of solar energy are then discussed: what it is, the variations in radiation at the earth's surface, measuring instruments, geographical distribution of radiation, etc.

The remaining chapters provide "state of the art" summations on each of several aspects of solar energy: collectors of solar radiation, cooking, heating water, agricultural and industrial drying, storage of heat, heating buildings, distillation of water, solar furnaces, selective radiation surfaces, cooling and refrigeration, heat engines, thermoelectric and thermoionic conversion, photovoltaic conversion, photochemical conversion and storage and transportation of power. In each instance, the chapter discussion is designed to interest non-technical readers while a comprehensive bibliography at the end is aimed at scientists and engineers interested in reviewing research in that particular area. A concluding chapter summarizes the main points of each chapter discussion and provides several general discussion references.

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Environmental Resource Packet Project
Department of Physics and Astronomy
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QUESTIONNAIRE

We are distributing this first packet of the ERP project free of charge. In return we ask you to fill out this brief questionnaire and return it to us after you have read through the packet. Your response will help us in the design of further packets and will keep your name on our mailing list for the packets to come.

In addition we will follow up at a later date with a one-page form asking for your comments after you have actually used the packet to present the topic in a course or public lecture. Your return of those comments will be of great importance to us as we make our decision on the future of the ERP Project.

Thank you for your cooperation.

John M. Fowler
Kathryn E. Mervine

Questions

1. This "Energy" packet will be followed by a packet on "Municipal Solid Waste and Recycling" which is nearing completion. Please rank in descending order of interest, 1 first, 2, 3, 4, etc., the topics below which are proposed for additional packets. We leave room for you to suggest topics we have neglected.

Topics	Rank	Topics	Rank
1. Air Pollution	☐	9. Land Use	☐
2. Water Pollution	☐	10. Trace Metal Contamination	☐
3. Population (hunger, crowding)	☐	11. Technological Assessment	☐
4. Natural Resource Management	☐	12. Environmental Effects of Modern War	☐
5. Noise	☐	13. Environmental Effects of Arms Race	☐
6. Transportation	☐	14.	☐
7. Communication	☐	15.	☐
8. Pesticides and Herbicides	☐	16.	☐

2. Please indicate the type of course and student audience (i.e. introductory course biology majors, organic chemistry, junior year, science students, etc.) for which you expect to use this packet.
Course _____ Students _____

3. Do you expect to use this packet to prepare for a public lecture or some similar community interaction? _____
Explain: _____

4. Have you criticism of the packet format, content or style? _____
_____
_____

5. Have you suggestions for making the reviews more detailed and explicit or do they appear to provide satisfactory guidance? (Would you like the articles ranked by our judgement of their importance?)
Satisfactory _____ Suggested changes: _____
_____

6. Would you be willing to pay an "at cost" charge (probably about $ 1./packet) for those packets which you wanted? Yes ____ No _____

7. Would you be interested in an arrangement which would provide for semi-annual updating of these packets at cost? Yes ____ No _____

over

Please put my name on the mailing list for additional packets. (If some cost is involved in distributing additional packets you will be notified.)

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Institution _____

Department _____

Address _____ Zip Code _____